QUAL2EU Results

Two thousand Monte Carlo simulations were run on each of the QUAL2EU input data sets. The simulation representing average annual conditions was compared to historical data at the gaging stations in the basin. Figure 20 shows a comparison of simulated average annual flow versus historical flow. The simulation results match the historical data very closely due to the calibration of the QUAL2EU model with historical discharge data. Information concerning calibration of the QUAL2EU model can be found in Appendix B.

The 2000 simulations also allow for examination of the simulated frequency distributions of discharge compared to historical distributions. Figure 21 shows this comparison for average annual conditions where the simulated gaging station locations are indicated by reach (r) and element (e) numbers and historical data are described with gaging station abbreviations (GS*). Note that the medians are very close but the ranges differ in some cases. The Monte Carlo simulations varied the base input discharge based on a specified coefficient of variation. A single coefficient of variation was accepted by the model to describe discharge variation, and hence, at all gaging station locations within the basin. The coefficient of variation was calculated at all gaging stations, based on historical data, and averaged across all gaging stations to obtain one value to describe the entire basin. It should be noted that this may not

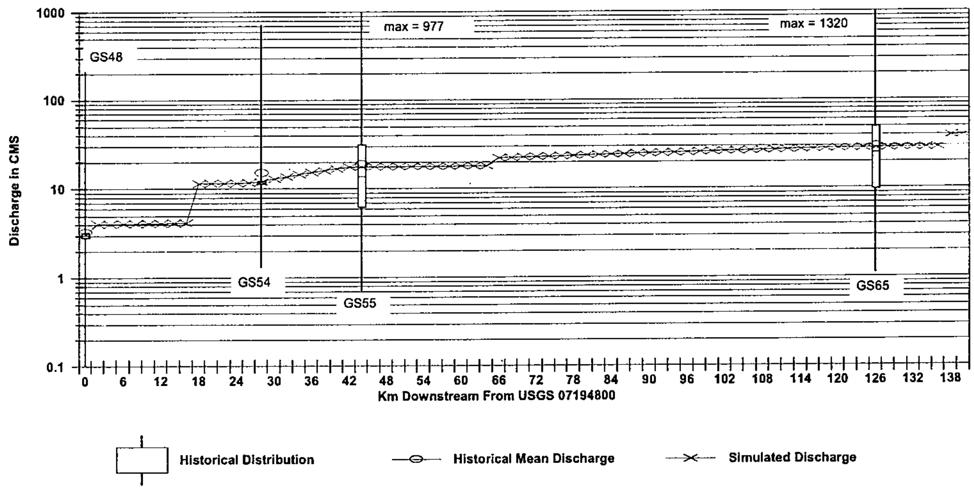

Figure 20. Simulated Annual Average Discharge Along the Mainstem of the Illinois River Compared with Historical Distributions of Discharge at USGS Gaging Stations.

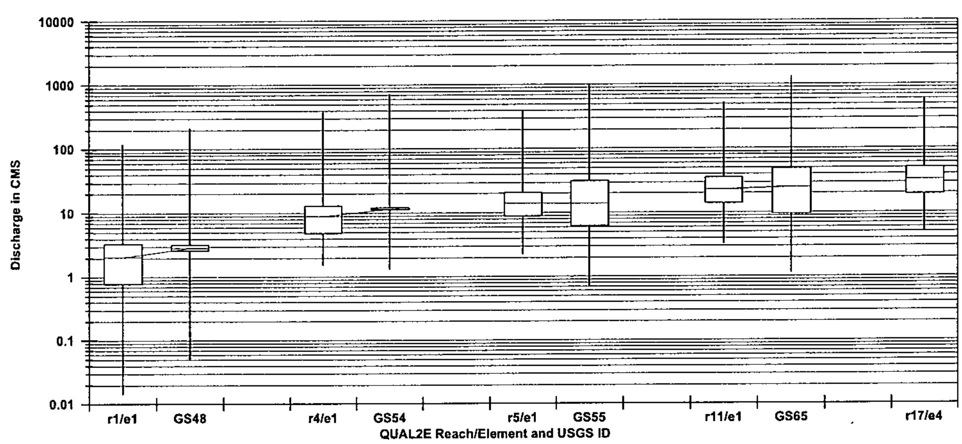

Figure 21. A Comparison of Simulated (r*/e*) and Historical (GS**)Discharge Distributions at Mainstem USGS Gaging Stations on the Illinois River.

accurately describe actual variation at each gage because of varying watershed size and characteristics.

Table XXXIX summarizes QUAL2EU simulation results for total phosphorus concentration at USGS gaging stations and the Horseshoe Bend area of Lake Tenkiller and these results are graphically compared to historical total phosphorus concentration distributions in Figure 22 . The model developed over-estimates average annual concentration but matches the historical data rather well on the mainstem of the Illinois River by maintaining average concentrations within the interquartile range of the historical data. An initial over-estimate occurs at USGS 07194800 (GS48 in Figure 22) as the SIMPLE model's predicted total phosphorus concentration is significantly greater than the historical annual average concentration.

Table XL summarizes average annual total nitrogen concentration results for the QUAL2EU model of the Illinois River basin. Figure 23 graphically compares mean simulated concentrations to historical distributions of total nitrogen at mainstem gaging stations. Again, the model over-estimates concentration when compared to the historical data, but in the mid and lower reaches of the mainstem, simulated concentrations do fall within the interquartile range of the historical data. The SIMPLE model's predicted total nitrogen concentration at USGS 07194800, the modeled Illinois River mainstem headwaters, is again significantly greater than the historical annual average concentration.

Figures 24 and 25 graphically compare distributions of simulated and

TABLE XXXIX

ESTIMATES OF AVERAGE ANNUAL TOTAL PHOSPHORUS CONCENTRATIONS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND (N=2000)

USGS Gaging Station Identification	Mean (mg/l)	Standard Deviation (mg/l)	Minimum (mg/l)	25th Percentile (mg/l)	50th Percentile (mg/l)	75th Percentile (mg/l)	Maximum (mg/l)
07194800	0.37	0.22	0.04	0.23	0.33	0.46	3.13
07195400	0.48	0.20	0.08	0.35	0.46	0.58	3.06
07195500	0.32	0.15	0.08	0.23	0.30	0.38	2.78
07196500	0.24	0.13	0.06	0.16	0.21	0.29	2.44
Horseshoe Bend	0.23	0.12	0.05	0.15	0.21	0.27	2.19
07195000	0.39	0.22	0.04	0.24	0.34	0.48	3.20
07196000	0.29	0.16	0.03	0.18	0.26	0.36	2.32
07196900	0.24	0.13	0.03	0.16	0.22	0.30	2.07
07197000	0.16	0.07	0.03	0.10	0.14	0.19	1.00

historical total phosphorus and total nitrogen concentrations, respectively. The model predicts a reasonable estimate of the measured distribution at most mainstem stations, with the possible exception of total phosphorus concentration at USGS 07194800.

Tables XLI through XLIII show the estimates of average annual total phosphorus concentrations, by source, at each of the USGS gages using simulated data. The simulation with zero point source nutrient inputs was subtracted from the average annual simulation to estimate point source contributions. In addition, a simulation was run estimating background concentrations of each nutrient. Nonpoint source nutrient concentrations were estimated by subtracting background simulation results from the simulation without point source nutrient inputs.

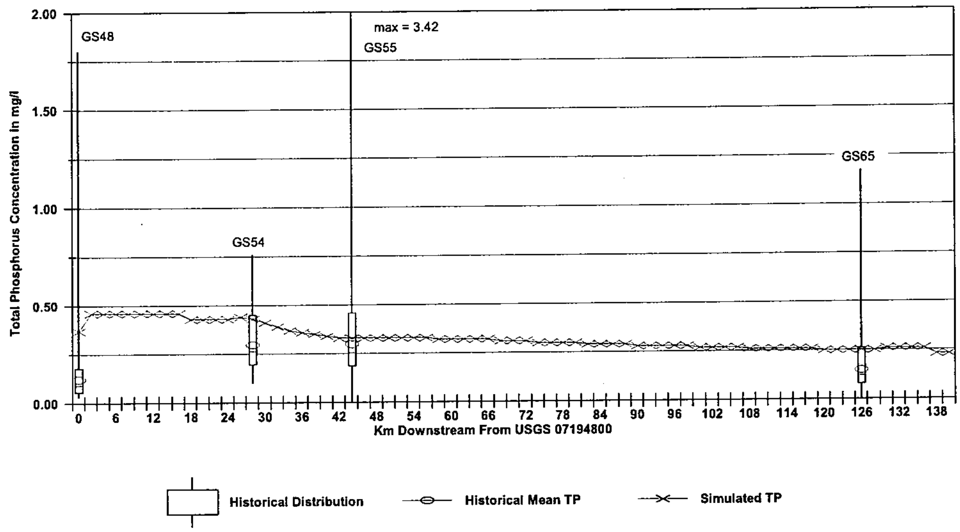

Figure 22. Simulated Average Annual Total Phosphorus Concentration Along the Mainstem of the Illinois River Compared to Historical Distributions at USGS Gaging Stations.

TABLE XL

ESTIMATES OF AVERAGE ANNUAL TOTAL NITROGEN CONCENTRATIONS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND (N=2000)

USGS Gaging Station Identification	Mean (mg/l)	Standard Deviation (mg/l)	Minimum (mg/l)	25th Percentile (mg/l)	50th Percentile (mg/l)	75th Percentile (mg/l)	Maximum (mg/l)
07194800	2.9	1.1	0.8	2.1	2.7	3.4	9.6
07195400	3.8	1.4	0.9	2.8	3.6	4.5	10.7
07195500	2.6	0.7	0.9	2.1	2.5	3.0	6.0
07196500	2.1	0.6	0.7	1.6	2.0	2.4	5.3
Horseshoe Bend	1.9	0.6	0.6	1.5	1.8	2.2	4.9
07195000	2.4	1.1	0.6	1.7	2.2	2.8	10.1
07196000	2.4	0.9	0.7	1.8	2.2	2.9	7.9
07196900	2.1	0.7	0.6	1.6	2.0	2.5	6.1
07197000	1.5	0.5	0.5	1.1	1.4	1.8	3.9

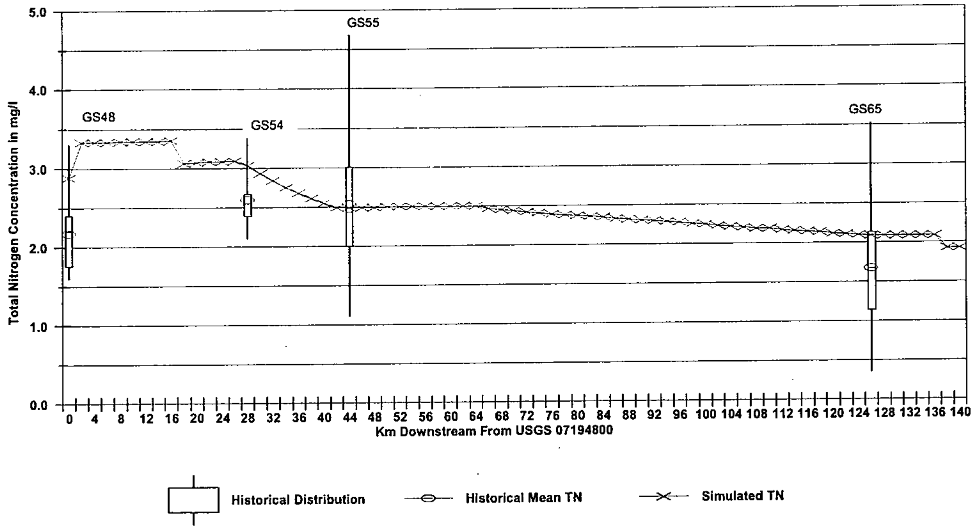

Figure 23. Simulated Average Annual Total Nitrogen Concentration Along the Mainstem of the Illinois River Compared to Historical Distributions at USGS Gaging Stations.

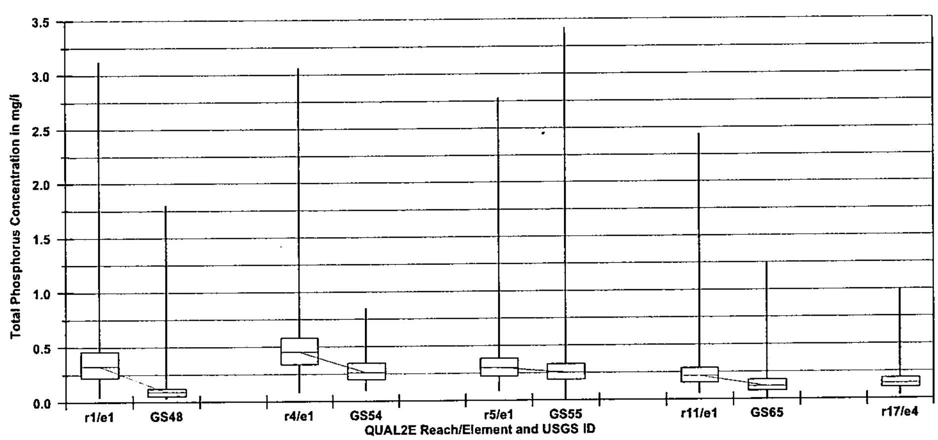

Figure 24. A Comparison of Simulated (r*/e*) and Historical (GS**) Total Phosphorus Distributions at Mainstem USGS Gaging Stations on the Illinois River.

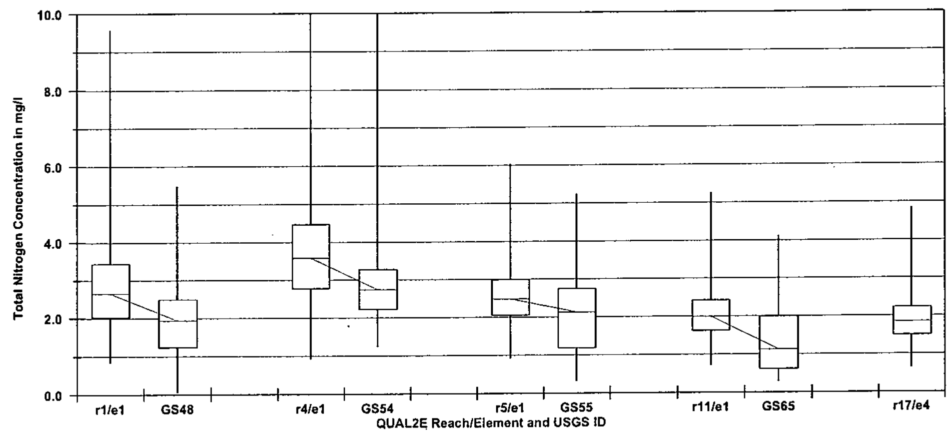

Figure 25. A Comparison of Simulated (r*/e*) and Historical (GS**)Total Nitrogen Distributions at Mainstem USGS Gaging Stations on the Illinois River.

This method may oversimplify the modeled system by ignoring probable nonlinearities, but it does provide useful estimates quantifying nutrients from each source. The simulated results then suggest that at Horseshoe Bend, where the mean annual concentration of total phosphorus was 0.23 mg/l, 0.15 mg/l (65.2%) are derived from nonpoint sources, 0.02 mg/l (8.7%) from background sources, and the remaining 0.06 mg/l (26.1%) from point sources.

TABLE XLI

ESTIMATES OF AVERAGE ANNUAL ANTHROPOGENIC NONPOINT SOURCE TOTAL PHOSPHORUS CONCENTRATIONS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND (N=2000)

USGS Gaging Station Identification	Mean (mg/l)	Standard Deviation (mg/l)	Minimum (mg/l)	25th Percentile (mg/l)	50th Percentile (mg/l)	75th Percentile (mg/l)	Maximum (mg/l)
07194800	0.34	0.20	0.04	0.21	0.30	0.42	2.87
07195400	0.35	0.16	0.04	0.24	0.33	0.43	1.52
07195500	0.23	0.09	0.04	0.16	0.21	0.27	1.39
07196500	0.16	0.07	0.04	0.11	0.15	0.20	1.28
Horseshoe Bend	0.15	0.07	0.04	0.10	0.14	0.18	1.20
07195000	0.13	0.08	0.01	0.08	0.12	0.16	0.94
07196000	0.20	0.11	0.02	0.12	0.17	0.24	1.43
07196900	0.21	0.11	0.03	0.13	0.19	0.25	1.66
07197000	0.12	0.06	0.02	0.08	0.11	0.15	0.80

TABLE XLII

ESTIMATES OF ANNUAL AVERAGE BACKGROUND TOTAL PHOSPHORUS CONCENTRATIONS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND (N=2000)

USGS Gaging Station Identification	Mean (mg/l)	Standard Deviation (mg/l)	Minimum (mg/l)	25th Percentile (mg/l)	50th Percentile (mg/l)	75th Percentile (mg/l)	Maximum (mg/l)
07194800	0.02	0.01	0.00	0.01	0.02	0.03	0.17
07195400	0.02	0.01	0.00	0.01	0.02	0.02	0.16
07195500	0.02	0.01	0.00	0.01	0.02	0.02	0.15
07196500	0.02	0.01	0.00	0.01	0.02	0.02	0.14
Horseshoe Bend	0.02	0.01	0.00	0.01	0.02	0.02	0.13
07195000	0.02	0.01	0.00	0.01	0.02	0.02	0.17
07196000	0.02	0.01	0.00	0.01	0.02	0.03	0.17
07196900	0.02	0.01	0.00	0.01	0.02	0.02	0.17
07197000	0.02	0.01	0.00	0.01	0.02	0.02	0.09

TABLE XLIII

ESTIMATES OF ANNUAL AVERAGE POINT SOURCE TOTAL PHOSPHORUS CONCENTRATIONS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND (N=2000)

USGS Gaging Station Identification	Mean (mg/l)	Standard Deviation (mg/l)	Minimum (mg/l)	25th Percentile (mg/l)	50th Percentile (mg/l)	75th Percentile (mg/l)	Maximum (mg/l)
07194800	0.01	0.01	0.00	0.01	0.01	0.01	0.09
07195400	0.12	0.03	0.04	0.10	0.11	0.13	1.38
07195500	0.08	0.05	0.04	0.05	0.07	0.09	1.25
07196500	0.06	0.05	0.01	0.03	0.05	0.07	1.02
Horseshoe Bend	0.06	0.04	0.01	0.04	0.06	0.08	0.87
07195000	0.24	0.13	0.03	0.15	0.21	0.29	2.09
07196000	0.08	0.04	0.01	0.05	0.07	0.10	0.72
07196900	0.02	0.01	0.00	0.01	0.02	0.02	0.25
07197000	0.02	0.00	0.01	0.01	0.02	0.02	0.11

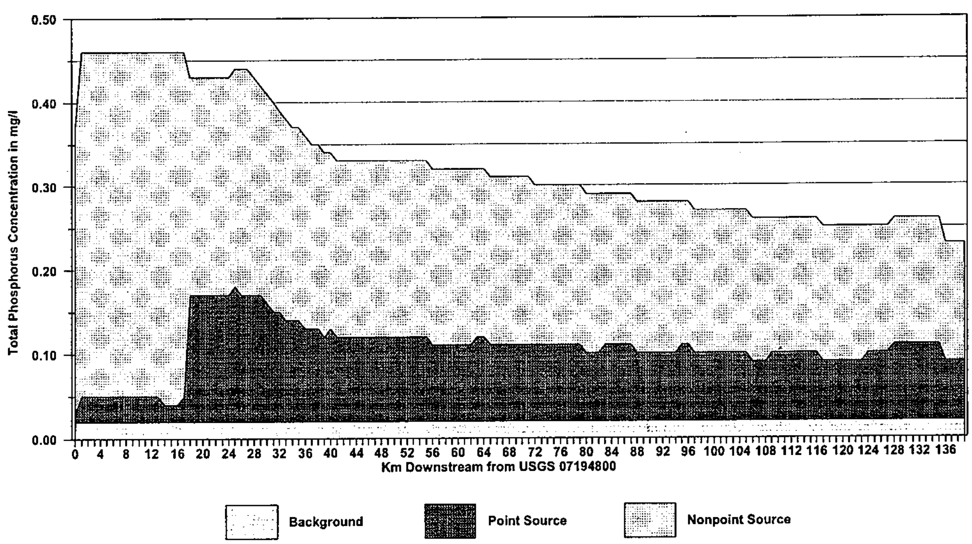

Figure 26. A Representation of the Fractions of Simulated Annual Average Total Phosphorus from Background, Point, and Nonpoint Sources Along the Mainstem of the Illinois River.

Figure 26 depicts graphically the simulated breakdown of the source of total phosphorus concentration on the mainstem of the Illinois River. The point source contribution jumps up at the point where Osage Creek enters the Illinois River, and gradually tapers downward proceeding toward Lake Tenkiller with the influence of Tahlequah's point source evident as another slight increase.

Similar tabular and graphical results were prepared for simulated total nitrogen concentration. Tables XLIV through XLVI describe the simulated breakdown of sources of total nitrogen concentration at USGS gaging station locations. Figure 27 graphically depicts the breakdown on the mainstem of the Illinois River. Again, using Horseshoe Bend as an example, the simulated average annual concentration of total nitrogen was 1.9 mg/l. Of this, 1.4 mg/l (71.8%) can be attributed to nonpoint sources, 0.5 mg/l (25.6%) to background sources, and only 0.05 mg/l (2.6%) attributable to point sources.

Table XLVII shows the relative errors of simulated versus historical total phosphorus and total nitrogen concentrations. It is evident that for total phosphorus there is consistent over-estimation of mean annual concentration at the gaging stations averaging just over 55%. The greatest difference is at USGS 07194800 (208%). The under-estimate of total phosphorus concentration at USGS 07195000 may be partly attributed to the point source in-stream assimilation method employed. Total nitrogen concentrations at the gaging stations was also over-estimated, although somewhat less, with an average relative error over all stations of nearly 24%. The greatest error occurs at USGS 07196500 with a 62% over-estimate. Again, USGS 07195000 shows a

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significant under-estimate (-48%).

TABLE XLIV

ESTIMATES OF ANNUAL AVERAGE NONPOINT SOURCE TOTAL NITROGEN CONCENTRATIONS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND (N=2000)

USGS Gaging Station Identification	Mean (mg/l)	Standard Deviation (mg/l)	Minimum (mg/l)	25th Percentile (mg/l)	50th Percentile (mg/l)	75th Percentile (mg/l)	Maximum (mg/l)
07194800	2.4	0.9	0.7	1.7	2.2	2.8	7.9
07195400	3.2	1.2	0.7	2.4	3.1	3.9	9.3
07195500	2.1	0.6	0.7	1.7	2.0	2.4	4.8
07196500	1.6	0.5	0.6	1.3	1.5	1.8	3.9
Horseshoe Bend	1.4	0.4	0.5	1.1	1.3	1.6	3.4
07195000	1.8	0.8	0.5	1.2	1.7	2.2	8.4
07196000	1.9	0.7	0.5	1.4	1.7	2.2	6.0
07196900	1.6	0.5	0.5	1.2	1.5	1.8	4.6
07197000	1.0	0.3	0.3	0.7	0.9	1.1	2.4

TABLE XLV

ESTIMATES OF ANNUAL AVERAGE BACKGROUND TOTAL NITROGEN CONCENTRATIONS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND (N=2000)

USGS Gaging Station Identification	Mean (mg/l)	Standard Deviation (mg/l)	Minimum (mg/l)	25th Percentile (mg/l)	50th Percentile (mg/l)	75th Percentile (mg/l)	Maximum (mg/l)
07194800	0.5	0.2	0.1	0.4	0.5	0.6	1.7
07195400	0.5	0.1	0.2	0.4	0.5	0.6	1.3
07195500	0.5	0.1	0.2	0.4	0.5	0.6	1.2
07196500	0.5	0.2	0.2	0.4	0.4	0.6	1.2
Horseshoe Bend	0.5	0.2	0.2	0.4	0.4	0.6	1.3
07195000	0.5	0.2	0.1	0.4	0.5	0.6	1.7
07196000	0.5	0.2	0.1	0.4	0.5	0.6	1.6
07196900	0.5	0.2	0.2	0.4	0.5	0.6	1.3
07197000	0.5	0.2	0.2	0.4	0.5	0.6	1.5

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TABLE XLVI

ESTIMATES OF AVERAGE ANNUAL POINT SOURCE TOTAL NITROGEN CONCENTRATIONS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND (N=2000)

USGS Gaging Station Identification	Mean (mg/l)	Standard Deviation (mg/l)	Minimum (mg/l)	25th Percentile (mg/l)	50th Percentile (mg/l)	75th Percentile (mg/l)	Maximum (mg/l)
07194800	0.00	0.00	0.00	0.00	0.00	0.00	0.00
07195400	0.05	0.00	0.02	0.04	0.05	0.05	0.06
07195500	0.03	0.01	0.02	0.02	0.03	0.04	0.02
07196500	0.03	0.01	0.01	0.03	0.04	0.03	0.12
Horseshoe Bend	0.05	0.01	0.02	0.05	0.06	0.07	0.14
07195000	0.07	0.02	0.02	0.05	0.06	0.08	0.06
07196000	0.07	0.03	0.02	0.05	0.06	0.08	0.24
07196900	0.04	0.02	0.00	0.03	0.04	0.06	0.18
07197000	0.04	0.01	0.01	0.03	0.04	0.05	0.02

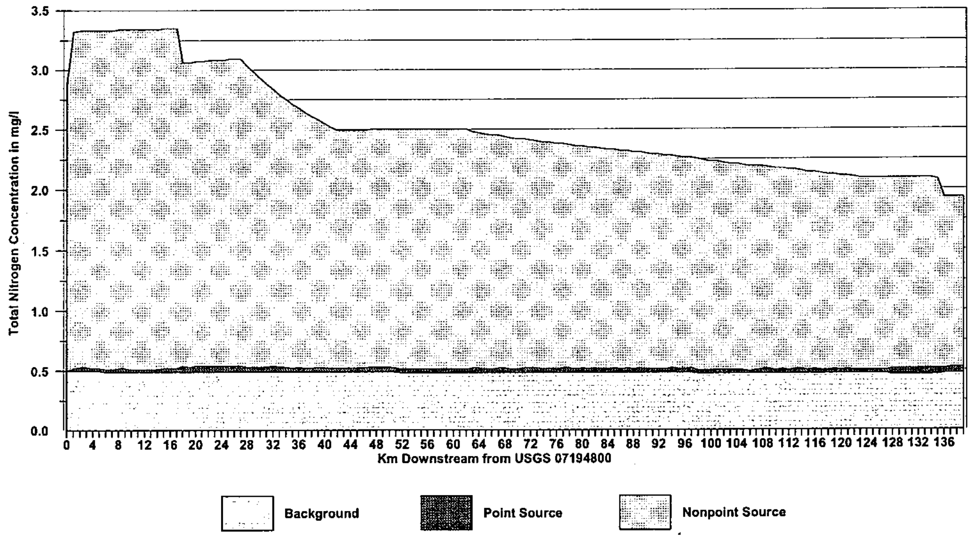

Figure 27. A Representation of the Fractions of Simulated Annual Average Total Nitrogen from Background, Point, and Nonpoint Sources Along the Mainstem of the Illinois River.

TABLE XLVII

RELATIVE ERRORS OF SIMULATED TOTAL PHOSPHORUS AND TOTAL NITROGEN CONCENTRATIONS COMPARED TO HISTORICAL DATA

USGS Gaging Station Identification	Historical Mean Total Phosphorus Conc. (mg/l)	Simulated Mean Total Phosphorus Conc. (mg/l)	Total Phosphorus Relative Error (%)	Historical Mean Total Nitrogen Conc. (mg/l)	Simulated Mean Total Nitrogen Conc. (mg/l)	Total Nitrogen Relative Error (%)
07194800	0.12	0.37	208	2.0	2.9	45
07195400	0.30	0.48	60	3.0	3.8	27
07195500	0.30	0.32	7	2.0	2.6	30
07196500	0.15	0.24	60	1.3	2.1	62
07195000	0.96	0.39	-59	4.6	3.8	-48
07196000	0.20	0.29	45	1.7	2.4	41
07196900	0.15	0.24	60	2.2	2.1	-5
07197000	0.10	0.16	60	1.1	1.5	36

Figure 28 compares simulated mean annual total phosphorus loading with historical distributions of annual average total phosphorus load at USGS gaging stations. The simulated mean loads fall outside the 75th percentiles of the historical loading data, but are relatively close when compared to historical mean values.

Tables L through LII describe simulated distributions of nonpoint, background, and point source total phosphorus loads, respectively. Using Horseshoe Bend as an example, where the simulated mean annual load was 291,000 kg/yr, 189,000 kg/yr (65%) can be attributed to nonpoint sources, 21,900 kg/yr (7.5%) to background sources, and the remaining 79,800 kg/yr (27.5%) to point sources. This compares reasonably well to historical data at Horseshoe Bend where the mean annual load was calculated to be 228,000 kg/yr, with 190,000 kg/yr (83.5%) coming from nonpoint sources, 25,000 kg/yr (11%) from background sources, and 12,500 kg/yr (5.5%) from point sources. The difference of 63,000 kg/yr in mean annual total phosphorus load can be explained mostly by the differing estimates in point source loads reaching Lake Tenkiller. On average, data at the eight USGS gaging stations correspond to that at Horseshoe Bend fairly well with an average 70% of the total phosphorus load coming from nonpoint sources, 7% from background sources, and 23% from point sources. Point sources contribute very little to the total phosphorus load at USGS 07194800 (2.6%), and a significant portion of the load at USGS 07195000 (60.2%).

Table XLIX summarizes the results for average annual total nitrogen loading at USGS gaging stations and the Horseshoe Bend area of Lake Tenkiller. The simulation estimates an annual average total nitrogen load of 2,4800,000 kg/yr entering Lake Tenkiller with an interquartile range of 947,000 to 3,510,000 kg/yr. These estimates also compare very well with previous loading estimates of total nitrogen at the Horseshoe Bend location based on historical data.

Figure 29 compares simulated average annual total nitrogen loading with historical distributions of annual average total nitrogen load at USGS gaging stations. Again, the simulated mean loads overestimate average annual loading when compared to historical data.

Tables LIII through LV describe simulated distributions of nonpoint, background, and point source total nitrogen loads, respectively. Using Horseshoe Bend as an example, where the simulated mean annual average load was 2,480,000 kg/yr, 1,800,000 kg/yr (72.7%) can be attributed to nonpoint sources, 605,000 kg/yr (24.5%) to background sources, and the remaining 69,500 kg/yr (2.8%) to point sources. This compares reasonably well to the estimates at Horseshoe Bend, based on historical data, of a mean annual total nitrogen load 2,300,000 kg/yr, where 73.4 % (1,690,000 kg/yr) was from nonpoint sources, 23.9% (550,000 kg/yr) from background sources, and 2.7% (61,600 kg/yr) from point sources. On average, data at the eight gaging stations compare well with the results at Horseshoe Bend with an average 77% from nonpoint sources, 21% from background sources, and 2% from point sources.

Table LVI lists relative errors of simulated total phosphorus and total nitrogen loads compared to historical mean loads at gaging stations and Horseshoe Bend. The greatest errors in simulated total phosphorus load are seen at USGS 07194800 (129%), a difference of 22,200 kg/yr, and USGS 07196900 (201%) with a difference of 7,950 kg/yr. Of the remaining seven sites, six were within 35% of the historical mean total phosphorus load. Simulated total nitrogen loading estimates corresponded fairly well with historical loading data with all nine sites within 30% of historical mean total nitrogen loading.

TABLE XLVIII

ESTIMATES OF ANNUAL AVERAGE TOTAL PHOSPHORUS LOADS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND (N=2000)

USGS Gaging Station Identification	Mean (kg/yr)	Standard Deviation (kg/yr)	Minimum (kg/yr)	25th Percentile (kg/yr)	50th Percentile (kg/yr)	75th Percentile (kg/yr)	Maximum (kg/yr)
07194800	39,400	108,000	19	5,720	21,100	47,800	11,800,000
07195400	197,300	467,000	3,940	54,000	127,000	235,000	36,700,000
07195500	189,000	375,000	5,750	63,800	132,000	249,000	33,400,000
07196500	223,000	425,000	5,730	70,900	154,000	316,000	40,400,000
Horseshoe Bend	291,000	521,000	8,270	95,400	211,000	429,000	39,600,000
07195000	88,700	243,000	55	13,100	47,800	107,000	26,100,000
07196000	37,400	102,000	31	5,650	20,400	45,300	10,500,000
07196900	11,900	29,000	93	2,800	7,280	14,300	3,050,000
07197000	51,200	83,600	1,420	18,700	39,200	78,200	1,970,000

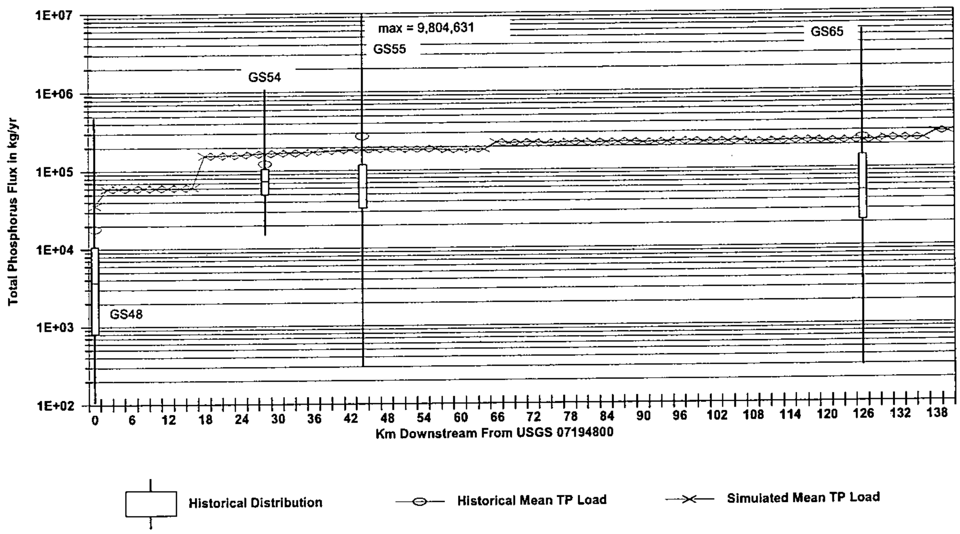

Figure 28. QUAL2EU Simulated Average Annual Total Phosphorus Load Compared to Historical Loading Distributions at Mainstem USGS Gaging Stations on the Illinois River.

TABLE XLIX

ESTIMATES OF ANNUAL AVERAGE TOTAL NITROGEN LOADS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND (N=2000)

USGS Gaging Station Identification	Mean (kg/yr)	Standard Deviation (kg/yr)	Minimum (kg/yr)	25th Percentile (kg/yr)	50th Percentile (kg/yr)	75th Percentile (kg/yr)	Maximum (kg/yr)
07194800	303,000	821,000	380	51,200	171,000	357,000	36,300,000
07195400	1,540,000	3,630,000	43,900	430,000	1,000,000	1,800,000	128,000,00 0
07195500	1,510,000	2,950,000	64,400	577,000	1,090,000	1,940,000	72,300,000
07196500	1,960,000	3,630,000	74,000	736,000	1,440,000	2,680,000	87,000,000
Horseshoe Bend	2,480,000	4,320,000	97,600	947,000	1,890,000	3,510,000	87,900,000
07195000	543,000	1,470,000	790	89,700	302,000	638,000	82,500,000
07196000	308,000	829,000	667	54,000	175,000	361,000	35,800,000
07196900	102,000	245,000	1,750	27,600	64,800	120,000	9,050,000
07197000	495,000	791,000	21,400	204,000	394,000	736,000	7,750,000

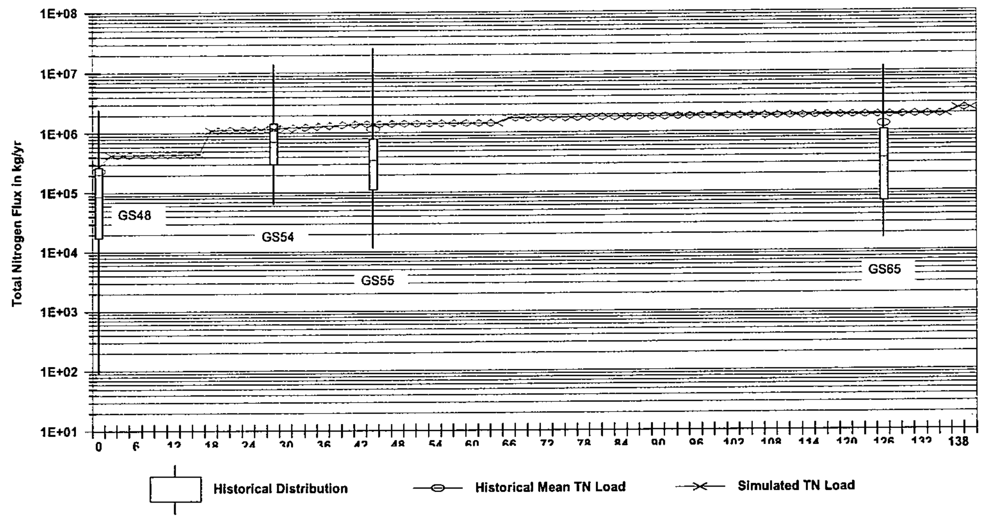

Figure 29. QUAL2EU Simulation Average Annual Total Nitrogen Load Compared to Historical Load Distributions at Mainstem USGS Gaging Stations on the Illinois River.

TABLE L

ESTIMATED AVERAGE ANNUAL NONPOINT SOURCE TOTAL PHOSPHORUS LOADS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND (N=2000)

USGS Gaging Station Identification	Mean (kg/yr)	Standard Deviation (kg/yr)	Minimum (kg/yr)	25th Percentile (kg/yr)	50th Percentile (kg/yr)	75th Percentile (kg/yr)	Maximum (kg/yr)
07194800	36,300	99,400	18	5,280	19,500	43,900	10,900,000
07195400	142,000	338,000	2,020	36,300	90,700	174,000	18,200,000
07195500	133,000	262,000	2,940	45,300	93,400	176,000	16,600,000
07196500	154,000	289,000	3,990	51,200	110,000	216,000	21,300,000
Horseshoe Bend	189,000	336,000	5,670	63,100	139,000	277,000	21,600,000
07195000	30,000	83,600	18	4,370	16,100	36,600	7,680,000
07196000	24,800	67,600	19	3,690	13,400	29,800	6,480,000
07196900	9,990	24,300	74	2,350	6,110	12,100	2,440,000
07197000	39,300	64,500	1,020	14,000	29,900	60,800	1,580,000

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TABLE LI

ESTIMATED AVERAGE ANNUAL BACKGROUND TOTAL PHOSPHORUS LOADS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND (N=2000)

USGS Gaging Station Identification	Mean (kg/yr)	Standard Deviation (kg/yr)	Minimum (kg/yr)	25th Percentile (kg/yr)	50th Percentile (kg/yr)	75th Percentile (kg/yr)	Maximum (kg/yr)
07194800	2,110	5,790	1	297	1,120	2,570	648,000
07195400	7,740	18,400	144	2,060	4,880	9,100	1,940,000
07195500	11,100	22,100	280	3,590	7,570	14,900	1,790,000
07196500	15,900	30,300	409	4,880	10,800	23,000	2,250,000
Horseshoe Bend	21,900	39,300	613	6,780	15,400	32,500	2,260,000
07195000	4,550	12,400	3	685	2,460	5,480	1,390,000
07196000	2,540	6,920	2	388	1,380	3,070	775,000
07196900	975	2,370	8	232	597	1,170	244,000
07197000	6,270	10,300	177	2,150	4,670	9,760	178,000

TABLE LII

ESTIMATED ANNUAL AVERAGE POINT SOURCE TOTAL PHOSPHORUS LOADS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND (N=2000)

USGS Gaging Station Identification	Mean (kg/yr)	Standard Deviation (kg/yr)	Minimum (kg/yr)	25th Percentile (kg/yr)	50th Percentile (kg/yr)	75th Percentile (kg/yr)	Maximum (kg/yr)
07194800	1,060	2,900	0	147	571	1,300	326,000
07195400	47,300	111,000	1,780	15,700	31,600	51,700	16,500,000
07195500	45,000	90,900	2,520	14,900	30,900	58,500	14,900,000
07196500	53,400	106,000	1,330	14,800	33,400	77,400	16,900,000
Horseshoe Bend	79,800	145,000	1,990	25,600	56,200	119,000	15,700,000
07195000	53,700	147,000	35	8,040	29,200	65,400	17,000,000
07196000	10,000	27,300	10	1,570	5,610	12,300	3,260,000
07196900	926	2,270	11	222	574	1,050	364,000
07197000	5,610	8,770	221	2,580	4,630	7,630	213,000

TABLE LIII

ESTIMATED AVERAGE ANNUAL NONPOINT SOURCE TOTAL NITROGEN LOADS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND (N=2000)

USGS Gaging Station Identification	Mean (kg/yr)	Standard Deviation (kg/yr)	Minimum (kg/yr)	25th Percentile (kg/yr)	50th Percentile (kg/yr)	75th Percentile (kg/yr)	Maximum (kg/yr)
07194800	251,000	680,000	315	42,500	142,000	295,000	30,000,000
07195400	1,320,000	3,120,000	34,800	364,000	857,000	1,560,000	112,000,000
07195500	1,210,000	2,360,000	50,300	464,000	877,000	1,550,000	57,600,000
07196500	1,480,000	2,750,000	57,200	561,000	1,090,000	2,030,000	64,600,000
Horseshoe Bend	1,800,000	3,140,000	71,100	689,000	1,380,000	2,540,000	62,300,000
07195000	415,000	1,130,000	582	67,800	230,000	489,000	68,400,000
07196000	237,000	637,000	509	41,600	135,000	277,000	27,200,000
07196900	75,700	182,000	1,320	20,500	48,100	88,300	6,830,000
07197000	320,000	511,000	13,500	132,000	256,000	478,000	4,830,000

TABLE LIV

ESTIMATED AVERAGE ANNUAL BACKGROUND TOTAL NITROGEN LOADS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND (N=2000)

USGS Gaging Station Identification	Mean (kg/yr)	Standard Deviation (kg/yr)	Minimum (kg/yr)	25th Percentile (kg/yr)	50th Percentile (kg/yr)	75th Percentile (kg/yr)	Maximum (kg/yr)
07194800	52,000	141,000	65	8,740	29,300	61,300	6,300,000
07195400	199,000	468,000	8,250	60,100	130,000	228,000	15,300,000
07195500	285,000	558,000	13,000	107,000	204,000	369,000	14,500,000
07196500	442,000	821,000	16,000	163,000	323,000	613,000	20,400,000
Horseshoe Bend	605,000	1,060,000	23,100	224,000	455,000	868,000	23,100,000
07195000	112,000	304,000	185	19,200	63,600	132,000	13,500,000
07196000	62,800	169,000	140	10,900	35,700	73,900	7,470,000
07196900	24,100	58,000	423	6,600	15,400	28,300	1,950,000
07197000	161,000	259,000	7,250	65,300	127,000	238,000	2,890,000

TABLE LV

ESTIMATED AVERAGE ANNUAL POINT SOURCE TOTAL NITROGEN LOADS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND (N=2000)

USGS Gaging Station Identification	Mean (kg/yr)	Standard Deviation (kg/yr)	Minimum (kg/yr)	25th Percentile (kg/yr)	50th Percentile (kg/yr)	75th Percentile (kg/yr)	Maximum (kg/yr)
07194800	0	0	0	0	0	0	0
07195400	18,300	42,500	816	6,060	13,700	18,000	659,000
07195500	15,800	30,600	1,050	6,050	11,900	23,900	240,000
07196500	31,800	58,900	1,020	12,500	25,500	34,600	2,040,000
Horseshoe Bend	69,500	120,000	3,370	33,200	56,200	102,000	2,460,000
07195000	15,200	40,900	23	2,640	8,610	17,300	513,000
07196000	8,390	22,600	18	1,450	4,830	9,780	1,090,000
07196900	2,150	5,210	8	506	1,270	3,000	269,000
07197000	12,900	20,200	619	6,020	11,100	19,700	37,500

TABLE LVI

RELATIVE ERRORS OF SIMULATED TOTAL PHOSPHORUS AND TOTAL NITROGEN LOADS COMPARED TO HISTORICAL DATA

USGS Gaging Station Identification	Historical Mean Annual Total Phosphorus Load (kg/yr)	Simulated Mean Annual Total Phosphorus Load (kg/yr)	Total Phosphorus Load Relative Error (%)	Historical Mean Annual Total Nitrogen Load (kg/yr)	Simulated Mean Annual Total Nitrogen Load (kg/yr)	Total Nitrogen Load Relative Error (%)
07194800	17,200	39,400	129	289,000	303,000	5
07195400	122,000	197,000	61	1,530,000	1,540,000	1
07195500	272,000	189,000	-31	1,280,000	1,510,000	18
07196500	241,000	223,000	-7	1,590,000	1,960,000	23
Horseshoe Bend	228,000	291,000	28	2,300,000	2,480,000	8
07195000	72,300	88,700	23	581,000	543,000	-7
07196000	48,200	37,400	-22	237,000	308,000	30
07196900	3,950	11,900	201	82,400	102,000	24
07197000	76,800	51,200	-33	417,000	495,000	19

Nonpoint sources were reduced by 25 and 50 percent to estimate the effects of this reduction on nutrient concentration and load at USGS gaging stations in the basin and the Horseshoe Bend area of Lake Tenkiller. Tables LVII - LXII describe statistically the estimated distributions of concentration and load for average annual conditions with a 25% decrease in nonpoint source loading. Only average annual and the nonpoint source data are given since the background and point source contributions were assumed to remain the same. The simulated annual mean total phosphorus concentration of 0.19 mg/l at

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Horseshoe Bend with a 25% reduction of NPS input compares with 0.23 mg/l under annual average conditions, a 17% decrease (Table LXIII). This translates into a mean load reduction of 50,000 kg/yr. It is estimated that mean total nitrogen load at Horseshoe Bend could be reduced 21% or 510,000 kg/yr with a 25% reduction of NPS inputs. The estimates at the gaging stations showed similar reduction with an average 19% decrease in total phosphorus concentration and 18% decrease in load. Total nitrogen concentrations and loads at the eight gaging stations were reduced an average 21% (Table LXIV).

Tables LXV through LXX show the estimated distributions of nutrient concentrations and loads with a 50% reduction of NPS inputs into the model. The mean total phosphorus load at Horseshoe Bend would be reduced by an estimated 102,000 kg/yr (35%), and the estimated mean total nitrogen load reduced by 1,020,000 kg/yr (41%). Over all nine sites, a 50% reduction in nonpoint source inputs reduced total phosphorus concentration and load by 36% (Table LXXI). For total nitrogen, concentration was reduced by 43%, and load was reduced by 42% (Table LXXII).

TABLE LVII

ESTIMATED AVERAGE ANNUAL TOTAL NITROGEN CONCENTRATIONS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND WITH 25% REDUCTION OF NONPOINT SOURCE INPUTS (N=2000)

USGS Gaging Station Identification	Mean (mg/l)	Standard Deviation (mg/l)	Minimum (mg/l)	25th Percentile (mg/l)	50th Percentile (mg/l)	75th Percentile (mg/l)	Maximum (mg/l)
07194800	2.2	0.9	0.6	1.6	2.1	2.7	7.4
07195400	2.9	1.0	0.7	2.2	2.8	3.4	8.2
07195500	2.0	0.6	0.7	1.6	1.9	2.3	4.7
07196500	1.7	0.5	0.6	1.3	1.6	1.9	4.2
Horseshoe Bend	1.5	0.5	0.5	1.2	1.5	1.8	3.8
07195000	1.9	0.8	0.5	1.3	1.7	2.3	7.7
07196000	1.9	0.7	0.6	1.4	1.8	2.3	6.3
07196900	1.7	0.6	0.5	1.3	1.6	2.0	4.9
07197000	1.2	0.4	0.4	0.9	1.2	1.4	3.2

TABLE LVIII

ESTIMATED AVERAGE ANNUAL TOTAL PHOSPHORUS CONCENTRATIONS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND WITH A 25% REDUCTION OF NONPOINT SOURCE INPUTS (N=2000)

USGS Gaging Station Identification	Mean (mg/l)	Standard Deviation (mg/l)	Minimum (mg/l)	25th Percentile (mg/l)	50th Percentile (mg/l)	75th Percentile (mg/l)	Maximum (mg/l)
07194800	0.29	0.16	0.03	0.18	0.25	0.35	2.39
07195400	0.40	0.16	0.07	0.29	0.37	0.47	2.67
07195500	0.26	0.13	0.07	0.18	0.24	0.31	2.42
07196500	0.20	0.11	0.04	0.13	0.17	0.23	2.11
Horseshoe Bend	0.19	0.10	0.04	0.12	0.17	0.22	1.88
07195000	0.36	0.20	0.04	0.22	0.31	0.44	2.96
07196000	0.24	0.14	0.03	0.15	0.22	0.30	1.95
07196900	0.19	0.10	0.03	0.12	0.17	0.23	1.65
07197000	0.12	0.06	0.03	0.08	0.11	0.15	0.79

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TABLE LIX

ESTIMATED AVERAGE ANNUAL TOTAL NITROGEN LOADS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND WITH A 25% REDUCTION OF NONPOINT SOURCE INPUTS (N=2000)

USGS Gaging Station Identification	Mean (kg/yr)	Standard Deviation (kg/yr)	Minimum (kg/yr)	25th Percentile (kg/yr)	50th Percentile (kg/yr)	75th Percentile (kg/yr)	Maximum (kg/yr)
07194800	234,000	634,000	293	39,500	132,000	276,000	28,100,000
07195400	1,180,000	2,800,000	34,500	334,000	770,000	1,380,000	97,600,000
07195500	1,180,000	2,320,000	50,600	453,000	857,000	1,520,000	57,000,000
07196500	1,550,000	2,870,000	58,000	580,000	1,140,000	2,120,000	68,800,000
Horseshoe Bend	1,970,000	3,440,000	77,500	753,000	1,510,000	2,790,000	69,500,000
07195000	433,000	1,170,000	634	72,000	242,000	511,000	62,700,000
07196000	243,000	655,000	528	42,700	139,000	286,000	28,400,000
07196900	81,000	195,000	1,400	21,900	51,400	95,000	7,180,000
07197000	404,000	646,000	17,600	166,000	322,000	599,000	6,370,000

TABLE LX

ESTIMATED AVERAGE ANNUAL TOTAL PHOSPHORUS LOADS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND WITH A 25% REDUCTION OF NONPOINT SOURCE INPUTS (N=2000)

USGS Gaging Station Identification	Mean (kg/yr)	Standard Deviation (kg/yr)	Minimum (kg/yr)	25th Percentile (kg/yr)	50th Percentile (kg/yr)	75th Percentile (kg/yr)	Maximum (kg/yr)
07194800	30,200	82,600	15	4,390	16,200	36,600	9,070,000
07195400	161,000	381,000	3,410	44,500	103,000	190,000	32,000,000
07195500	154,000	308,000	4,840	51,200	106,000	203,000	29,100,000
07196500	183,000	350,000	4,400	56,900	125,000	258,000	34,900,000
Horseshoe Bend	241,000	432,000	6,590	78,300	174,000	354,000	34,000,000
07195000	80,800	221,000	51	11,900	43,400	98,000	24,100,000
07196000	31,000	84,500	26	4,700	16,900	37,600	8,860,000
07196900	9,310	22,700	71	2,180	5,690	11,200	2,420,000
07197000	40,900	66,900	1,150	15,000	31,500	62,500	1,560,000

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TABLE LXI

ESTIMATED AVERAGE ANNUAL NONPOINT SOURCE TOTAL NITROGEN LOADS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND WITH A 25% REDUCTION OF NONPOINT SOURCE INPUTS (N=2000)

USGS Gaging Station Identification	Mean (kg/yr)	Standard Deviation (kg/yr)	Minimum (kg/yr)	25th Percentile (kg/yr)	50th Percentile (kg/yr)	75th Percentile (kg/yr)	Maximum (kg/yr)
07194800	182,000	494,000	227	30,800	103,000	214,000	21,800,000
07195400	964,000	2,280,000	25,400	268,000	626,000	1,140,000	81,600,000
07195500	884,000	1,730,000	36,600	340,000	641,000	1,130,000	42,200,000
07196500	1,070,000	1,990,000	41,200	404,000	788,000	1,470,000	46,400,000
Horseshoe Bend	1,300,000	2,260,000	51,000	495,000	996,000	1,820,000	43,900,000
07195000	306,000	829,000	426	50,100	170,000	362,000	48,700,000
07196000	172,000	463,000	370	30,300	98,200	202,000	19,900,000
07196900	54,700	132,000	968	14,800	34,700	63,500	4,960,000
07197000	230,000	367,000	9,690	95,200	184,000	342,000	3,450,000

TABLE LXII

ESTIMATED AVERAGE ANNUAL NONPOINT SOURCE TOTAL PHOSPHORUS LOADS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND WITH A 25% REDUCTION OF NONPOINT SOURCE INPUTS (N=2000)

USGS Gaging Station Identification	Mean (kg/yr)	Standard Deviation (kg/yr)	Minimum (kg/yr)	25th Percentile (kg/yr)	50th Percentile (kg/yr)	75th Percentile (kg/yr)	Maximum (kg/yr)
07194800	27,000	74,000	14	3,950	14,500	32,700	8,090,000
07195400	106,000	252,000	1,490	26,700	67,000	129,000	13,500,000
07195500	98,100	195,000	2,030	32,700	67,700	130,000	12,400,000
07196500	113,000	214,000	2,660	37,200	81,000	157,000	15,800,000
Horseshoe Bend	139,000	248,000	3,980	46,000	102,000	203,000	16,100,000
07195000	22,500	61,900	14	3,140	11,700	27,200	5,670,000
07196000	18,400	50,300	14	2,740	9,900	22,200	4,820,000
07196900	7,410	18,100	52	1,720	4,520	9,000	1,810,000
07197000	29,100	47,800	752	10,300	22,200	45,100	1,170,000

TABLE LXIII

RELATIVE REDUCTION IN MEAN ANNUAL TOTAL PHOSPHORUS CONCENTRATION AND LOAD WITH A 25% REDUCTION IN NONPOINT SOURCE INPUTS

USGS Gaging Station Identification	Simulated Mean Annual Total Phosphorus Conc. (mg/l)	Simulated Mean Annual Total Phosphorus Conc. With 25% NPS Reduction (mg/l)	Change (%)	Simulated Mean Annual Total Phosphorus Load (kg/yr)	Simulated Mean Annual Total Phosphorus Load With 25% NPS Reduction (kg/yr)	Change (%)
07194800	0.37	0.29	-22	39,400	30,200	-23
07195400	0.48	0.40	-17	197,000	161,000	-18
07195500	0.32	0.26	-19	189,000	154,000	-19
07196500	0.24	0.20	-17	223,000	183,000	-18
Horseshoe Bend	0.23	0.19	-17	291,000	241,000	-17
07195000	0.39	0.36	-17	88,700	80,800	-9
07196000	0.29	0.24	-17	37,400	31,000	-17
07196900	0.24	0.19	-21	11,900	9,310	-22
07197000	0.16	0.12	-25	51,200	40,900	-20

TABLE LXIV

RELATIVE REDUCTION IN MEAN ANNUAL TOTAL NITROGEN CONCENTRATION AND LOAD WITH A 25% REDUCTION IN NONPOINT SOURCE INPUTS

USGS Gaging Station Identification	Simulated Mean Annual Total Nitrogen Conc. (mg/l)	Simulated Mean Annual Total Nitrogen Conc. With 25% NPS Reduction (mg/l)	Change (%)	Simulated Mean Annual Total Nitrogen Load (kg/yr)	Simulated Mean Annual Total Nitrogen Load With 25% NPS Reduction (kg/yr)	Change (%)
07194800	2.9	2.2	-24	303,000	234,000	-23
07195400	3.8	2.9	-24	1,540,000	1,180,000	-23
07195500	2.6	2.0	-23	1,510,000	1,180,000	-22
07196500	2.1	1.7	-19	1,960,000	1,550,000	-21
Horseshoe Bend	1.9	1.5	-21	2,480,000	1,970,000	-21
07195000	2.4	1.9	-21	543,000	433,000	-20
07196000	2.4	1.9	-21	308,000	243,000	-21
07196900	2.1	1.7	-19	102,000	81,000	-21
07197000	1.5	1.2	-20	495,000	404,000	-18

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TABLE LXV

ESTIMATED AVERAGE ANNUAL TOTAL NITROGEN CONCENTRATIONS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND WITH A 50% REDUCTION IN NONPOINT SOURCE INPUTS (N=2000)

USGS Gaging Station Identification	Mean (mg/l)	Standard Deviation (mg/l)	Minimum (mg/l)	25th Percentile (mg/l)	50th Percentile (mg/l)	75th Percentile (mg/l)	Maximum (mg/l)
07194800	1.6	0.5	0.6	1.1	1.4	1.9	5.2
07195400	2.0	0.5	0.7	1.5	1.9	2.4	5.6
07195500	1.5	0.5	0.4	1.2	1.4	1.7	3.5
07196500	1.2	0.4	0.4	0.9	1.2	1.4	3.0
Horseshoe Bend	1.1	0.4	0.4	0.9	1.1	1.3	2.8
07195000	1.4	0.4	0.6	1.0	1.3	1.7	5.3
07196000	1.4	0.4	0.5	1.0	1.3	1.7	4.6
07196900	1.2	0.4	0.4	0.9	1.2	1.4	3.6
07197000	0.9	0.3	0.3	0.7	0.9	1.1	2.5

TABLE LXVI

ESTIMATED AVERAGE ANNUAL TOTAL PHOSPHORUS CONCENTRATIONS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND WITH A 50% REDUCTION IN NONPOINT SOURCE INPUTS (N=2000)

USGS Gaging Station Identification	Mean (mg/l)	Standard Deviation (mg/l)	Minimum (mg/l)	25th Percentile (mg/l)	50th Percentile (mg/l)	75th Percentile (mg/l)	Maximum (mg/l)
07194800	0.20	0.11	0.02	0.12	0.17	0.24	1.66
07195400	0.30	0.13	0.06	0.22	0.28	0.36	2.27
07195500	0.21	0.11	0.05	0.14	0.18	0.24	2.06
07196500	0.15	0.09	0.03	0.10	0.13	0.18	1.77
Horseshoe Bend	0.15	0.08	0.03	0.10	0.13	0.18	1.56
07195000	0.32	0.18	0.04	0.20	0.28	0.39	2.70
07196000	0.19	0.11	0.02	0.12	0.17	0.24	1.58
07196900	0.14	0.07	0.02	0.09	0.12	0.17	1.21
07197000	0.09	0.04	0.02	0.06	0.08	0.11	0.58

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TABLE LXVII

ESTIMATED AVERAGE ANNUAL TOTAL NITROGEN LOADS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND WITH A 50% REDUCTION IN NONPOINT SOURCE INPUTS (N=2000)

USGS Gaging Station Identification	Mean (kg/yr)	Standard Deviation (kg/yr)	Minimum (kg/yr)	25th Percentile (kg/yr)	50th Percentile (kg/yr)	75th Percentile (kg/yr)	Maximum (kg/yr)
07194800	165,000	448,000	207	27,900	93,300	194,000	19,800,000
07195400	822,000	1,940,000	25,000	23,600	538,000	959,000	67,100,000
07195500	854,000	1,670,000	36,800	325,000	616,000	1,100,000	41,500,000
07196500	1,130,000	2,100,000	42,000	422,000	830,000	1,560,000	50,200,000
Horseshoe Bend	1,460,000	2,550,000	57,300	555,000	1,110,000	2,080,000	50,800,000
07195000	321,000	870,000	482	53,900	180,000	380,000	42,800,000
07196000	177,000	478,000	388	31,100	101,000	208,000	20,900,000
07196900	59,700	143,000	1,040	16,200	37,900	69,700	5,270,000
07197000	312,000	499,000	13,600	129,000	248,000	461,000	5,000,000

TABLE LXVIII

ESTIMATED AVERAGE ANNUAL TOTAL PHOSPHORUS LOADS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND WITH A 50% REDUCTION IN NONPOINT SOURCE INPUTS (N=2000)

USGS Gaging Station Identification	Mean (kg/yr)	Standard Deviation (kg/yr)	Minimum (kg/yr)	25th Percentile (kg/yr)	50th Percentile (kg/yr)	75th Percentile (kg/yr)	Maximum (kg/yr)
07194800	20,900	57,200	10	3,030	11,200	25,300	6,290,000
07195400	124,000	294,000	2,830	34,300	79,400	145,000	27,200,000
07195500	112,000	240,000	3,650	38,700	81,300	157,000	24,700,000
07196500	142,000	275,000	3,070	43,100	96,600	202,000	29,300,000
Horseshoe Bend	189,000	342,000	4,900	60,500	136,000	279,000	28,300,000
07195000	72,600	199,000	46	10,600	39,100	88,200	22,000,000
07196000	24,500	66,800	20	3,710	13,300	29,700	7,140,000
07196900	6,730	16,400	52	1,570	4,110	8,110	1,780,000
07197000	30,400	49,600	884	11,200	23,600	46,300	1,150,000

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TABLE LXIX

ESTIMATED AVERAGE ANNUAL NONPOINT SOURCE TOTAL NITROGEN LOADS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND WITH A 50% REDUCTION IN NONPOINT SOURCE INPUTS (N=2000)

USGS Gaging Station Identification	Mean (kg/yr)	Standard Deviation (kg/yr)	Minimum (kg/yr)	25th Percentile (kg/yr)	50th Percentile (kg/yr)	75th Percentile (kg/yr)	Maximum (kg/yr)
07194800	113,000	307,000	142	19,200	64,000	133,000	13,600,000
07195400	605,000	1,430,000	15,900	170,000	394,000	713,000	51,100,000
07195500	553,000	1,080,000	22,800	213,000	400,000	704,000	26,700,000
07196500	659,000	1,220,000	25,200	247,000	482,000	912,000	27,800,000
Horseshoe Bend	789,000	1,370,000	30,800	298,000	603,000	1,110,000	25,300,000
07195000	194,000	525,000	274	32,000	108,000	231,000	28,800,000
07196000	106,000	286,000	230	18,700	60,600	125,000	12,400,000
07196900	33,400	80,300	611	9,080	21,200	38,500	3,050,000
07197000	138,000	220,000	5,750	57,400	111,000	203,000	2,080,000

TABLE LXX

ESTIMATED AVERAGE ANNUAL NONPOINT SOURCE TOTAL PHOSPHORUS LOADS AT LOCATIONS CORRESPONDING TO USGS GAGING STATIONS AND HORSESHOE BEND WITH A 50% REDUCTION IN NONPOINT SOURCE INPUTS (N=2000)

USGS Gaging Station Identification	Mean (kg/yr)	Standard Deviation (kg/yr)	Minimum (kg/yr)	25th Percentile (kg/yr)	50th Percentile (kg/yr)	75th Percentile (kg/yr)	Maximum (kg/yr)
07194800	17,700	48,500	9	2,590	9,520	21,500	5,310,000
07195400	68,900	165,000	912	16,500	42,900	84,400	8,730,000
07195500	63,700	127,000	841	20,200	42,800	83,900	7,990,000
07196500	73,000	139,000	1,330	23,400	52,400	102,000	10,200,000
Horseshoe Bend	87,500	157,000	2,300	28,100	63,900	128,000	10,400,000
07195000	14,300	39,600	9	1,920	7,360	17,300	3,590,000
07196000	11,900	32,600	9	1,750	6,330	14,300	3,100,000
07196900	4,830	11,800	33	1,120	2,930	5,890	1,170,000
07197000	18,500	30,400	486	6,510	14,200	28,900	754,000

TABLE LXXI

RELATIVE REDUCTION IN MEAN ANNUAL TOTAL PHOSPHORUS CONCENTRATION AND LOAD WITH A 50% REDUCTION IN NONPOINT SOURCE INPUTS

USGS Gaging Station Identification	Simulated Mean Annual Total Phosphorus Conc. (mg/l)	Simulated Mean Annual Total Phosphorus Conc. With 50% NPS Reduction (mg/l)	Change (%)	Simulated Mean Annual Total Phosphorus Load (kg/yr)	Simulated Mean Annual Total Phosphorus Load With 50% NPS Reduction (kg/yr)	Change (%)
07194800	0.37	0.20	-46	39,400	20,900	-47
07195400	0.48	0.30	-38	197,000	124,000	-37
07195500	0.32	0.21	-34	189,000	120,000	-37
07196500	0.24	0.15	-38	223,000	142,000	-36
Horseshoe Bend	0.23	0.15	-35	291,000	189,000	-35
07195000	0.39	0.32	-18	88,700	72,600	-18
07196000	0.29	0.19	-34	37,400	24,500	-34
07196900	0.24	0.14	-42	11,900	6,730	-43
07197000	0.16	0.09	-44	51,200	30,400	-41

TABLE LXXII

RELATIVE REDUCTION IN MEAN ANNUAL TOTAL NITROGEN CONCENTRATION AND LOAD WITH A 50% REDUCTION IN NONPOINT SOURCE INPUTS

USGS Gaging Station Identificatio n	Simulated Mean Annual Total Nitrogen Conc. (mg/l)	Simulated Mean Annual Total Nitrogen Conc. With 50% NPS Reduction (mg/l)	Chang e (%)	Simulated Mean Annual Total Nitrogen Load (kg/yr)	Simulated Mean Annual Total Nitrogen Load With 50% NPS Reduction (kg/yr)	Chang e (%)
07194800	2.9	1.6	-45	303,000	165,000	-46
07195400	3.8	2.0	-47	1,540,000	822,000	-47
07195500	2.6	1.5	-42	1,510,000	854,000	-43
07196500	2.1	1.2	-43	1,960,000	1,130,000	-42
Horseshoe Bend	1.9	1.1	-42	2,480,000	1,460,000	-41
07195000	2.4	1.4	-42	543,000	321,000	-41
07196000	2.4	1.4	-42	308,000	177,000	-43
07196900	2.1	1.2	-43	102,000	59,700	-41
07197000	1.5	0.9	-40	495,000	312,000	-37

CHAPTER VI

DISCUSSION

The focus of the study was on the quantities of nutrients delivered to the upper portion of Lake Tenkiller at the Horseshoe Bend area and the sources of those nutrients. The modeling scheme allowed for the estimation of frequency distributions of average annual nutrient concentrations and loadings at this point, as well as, estimates of contributions by point, nonpoint, and background sources.

The SIMPLE model provided estimates of runoff generated nonpoint source phosphorus delivered to the stream. Based on the SIMPLE model, areas with high soil phosphorus levels, due to long-term application of chicken litter, were shown to be the greatest contributors to nonpoint phosphorus at the Horseshoe Bend Area. Figure 30 shows estimated annual average total phosphorus loading from the subbasins above Lake Tenkiller based on the SIMPLE model. Subbasins OSAGE, FORK, BARON, FLINT, BENTON, and CLEAR were shown to deliver the greatest quantities. The SIMPLE model did not predict nonpoint nitrogen export from the subbasins. Unit-area loading methods were applied to estimate average annual total nitrogen export from each of the subbasins. Figure 31 indicates that total nitrogen export from the subbasins above Lake Tenkiller is dominated by seven subbasins (OSAGE, FORK, BARON, BENTON, BORD, and FLINT).

The QUAL2EU model used SIMPLE phosphorus export estimates, and unit area total nitrogen loading estimates from each of the subbasins and routed them downstream to Lake Tenkiller. The following pie graphs describe the estimated mean relative distributions of sources of nutrient concentrations at Horseshoe Bend under annual average, and 25% and 50% reductions of nonpoint source inputs (Figures 32 - 37) based on the QUAL2EU model. For obvious reasons, as nonpoint source contributions are decreased, point and background contributions increase.

Nonpoint contributions to total phosphorus and total nitrogen concentration are estimated to be 60.9% and 73.1%, respectively (Figures 32 and 37). With a 25% reduction of nonpoint source inputs, these percentages drop to 52.6% and 66% of total phosphorus and total nitrogen concentrations, respectively (Figures 34 and 35). A 50% reduction of nonpoint source total phosphorus and total nitrogen indicates a potential decrease in nonpoint contributions to concentration at Horseshoe Bend down to 40% and 54% of total phosphorus and total nitrogen, respectively (Figures 36 and 37). Total phosphorus point source contributions are estimated to contribute 30.4% to total phosphorus concentration under average annual conditions, and this percentage increases to 46.7% with a 50% decrease in nonpoint sources. Point sources are estimated to contribute 2.6% of the total nitrogen concentration under average

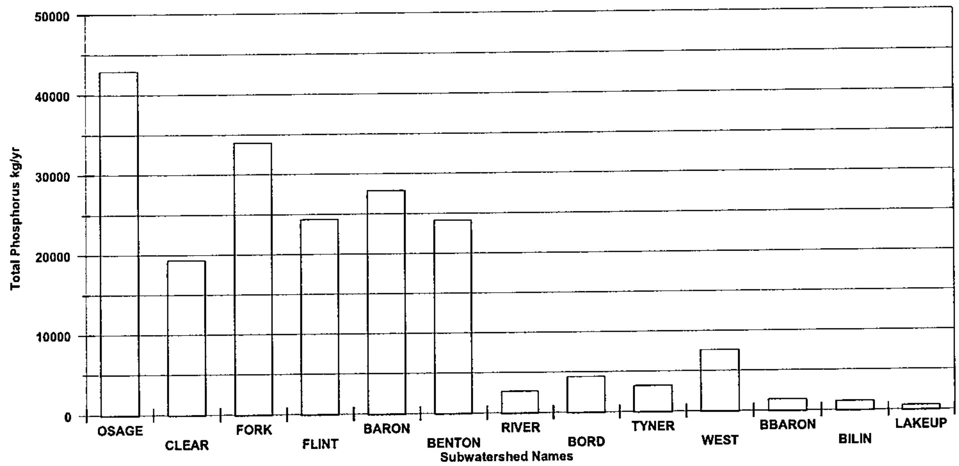

Figure 30. SIMPLE Estimated Average Annual Total Phosphorus Loads From Subbasins Above the Horseshoe Bend Area of Lake Tenkiller.

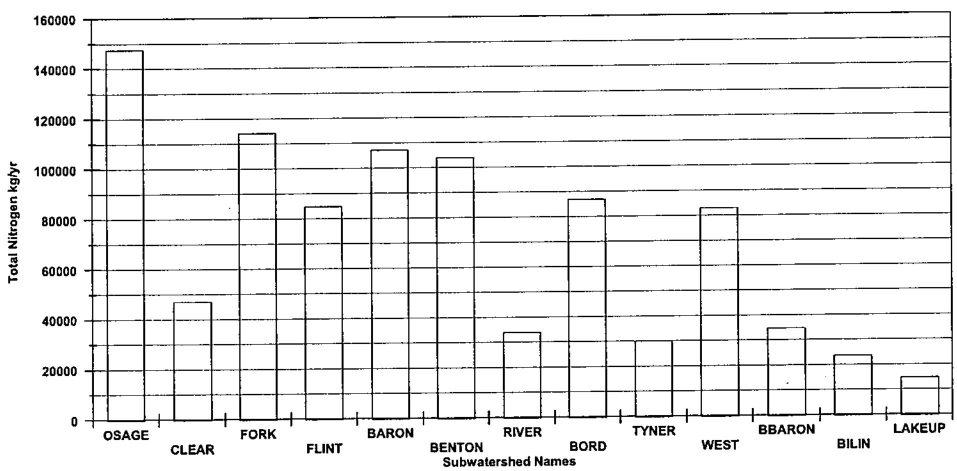

Figure 31. Unit Area Loading Estimates of Average Annual Total Nitrogen Loads From Subbasins Above the Horseshoe Bend Area of Lake Tenkiller.

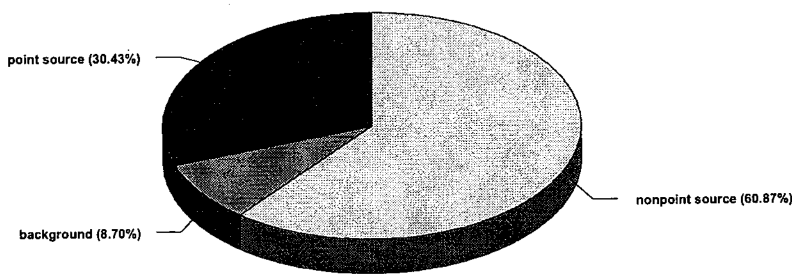

Figure 32. Estimates of Percent Contributions of Point, Nonpoint, and Background Sources to Average Annual Total Phosphorus Concentration at Horseshoe Bend Under Average Annual Conditions.

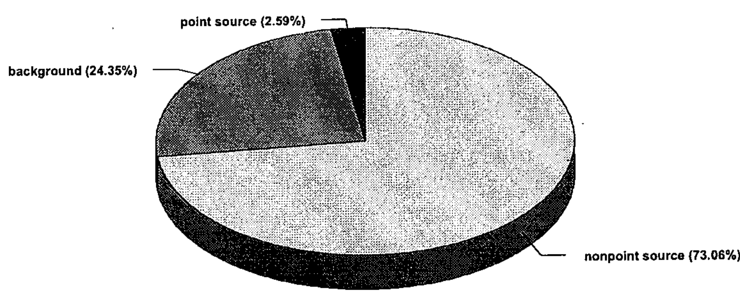

Figure 33. Estimates of Percent Contributions of Point, Nonpoint, and Background Sources to Average Annual Total Nitrogen Concentration at Horseshoe Bend Under Average Annual Conditions.

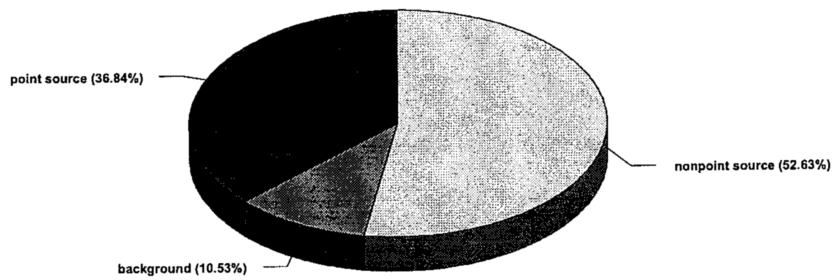

Figure 34. Estimates of the Percent Contributions of Point, Nonpoint, and Background Sources to Total Phosphorus Concentration at Horseshoe Bend with a 25% Reduction of Nonpoint Source Total Phosphorus.

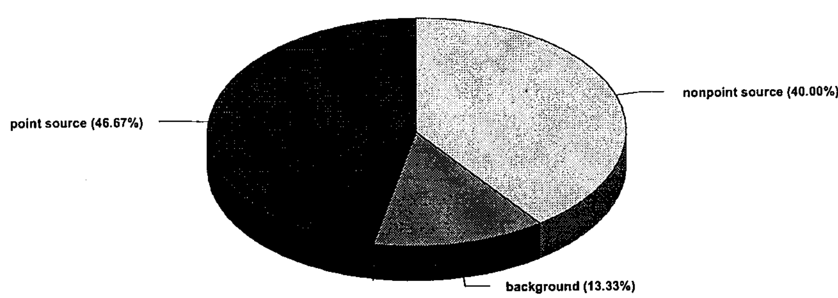

Figure 35. Estimates of the Percent Contributions of Point, Nonpoint, and Background Sources to Total Phosphorus Concentration at Horseshoe Bend with a 50% Reduction of Nonpoint Source Total Phosphorus.

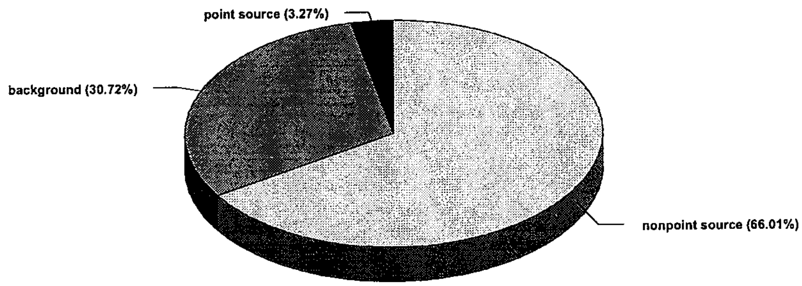

Figure 36. Estimates of the Percent Contributions of Point, Nonpoint, and Background Sources to Total Nitrogen Concentration at Horseshoe Bend with a 25% Reduction of Nonpoint Source Total Nitrogen.

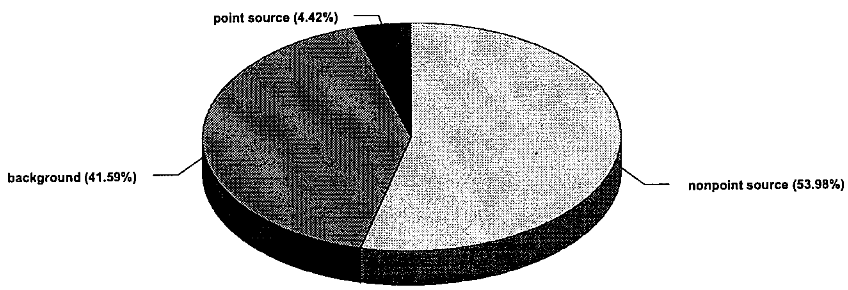

Figure 37. Estimates of the Percent Contributions of Point, Nonpoint, and Background Sources to Total Nitrogen Concentration at Horseshoe Bend with a 50% Reduction of Nonpoint Source Total Nitrogen.

annual conditions, and this increases to 4.4% with a 50% decrease in nonpoint source inputs.

Pie graphs (Figures 38 through 43) were prepared to depict the contributions of different sources of nutrient loads at gaging stations on the mainstem of the Illinois River and Horseshoe Bend under average annual conditions and with reductions of nonpoint source inputs. Figure 38 shows that under average annual conditions, in the upper part of the Illinois River Basin (USGS 07194800) nonpoint sources of total phosphorus dominate total load. USGS 07195400, 07195500, and 07196500 all show relatively similar contributions of nonpoint sources to total phosphorus load at close to 70%. Horseshoe Bend shows the effects of Tahlequah point source influence and the confluence of the Baron Fork Creek with the Illinois River, in that the nonpoint contribution is reduced to nearly 65% while the point source contribution increases.

Figure 39 shows the same type of information for total nitrogen loading. The upper reaches of the basin, represented by USGS 07194800, show little influence of point sources with nonpoint sources comprising over 80% of the total load. Along the mainstem of the Illinois River represented by USGS 07195400, 07195500, and 07196500, point sources contribute just over 1% of total load while nonpoint sources contribute near 80% of the total load. Again, the Horseshoe Bend area of Lake Tenkiller shows the influence of Tahlequah's point source input and the confluence of the Baron Fork Creek with the Illinois River. Figures 40 and 41 show estimates of contributions of point, nonpoint, and

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background sources to total phosphorus loads with reductions in nonpoint source inputs. With a 25% reduction in nonpoint source inputs, point source contributions to total phosphorus loads increase about 5% while nonpoint source contributions decrease 6 to 7%. Fifty percent reductions in nonpoint source inputs result in even greater shifts with point sources contributing over 35% of the total phosphorus load at stations 07195400, 07195500, and 07196500, and over 40% at Horseshoe Bend.

A similar analysis of total nitrogen loads with reductions in nonpoint source inputs (Figures 42 and 43) show that point sources of total nitrogen contribute significantly less to total nitrogen loads. Significant changes are only seen in the relative contributions of background and nonpoint sources. As nonpoint source inputs are decreased, background contribution increase.

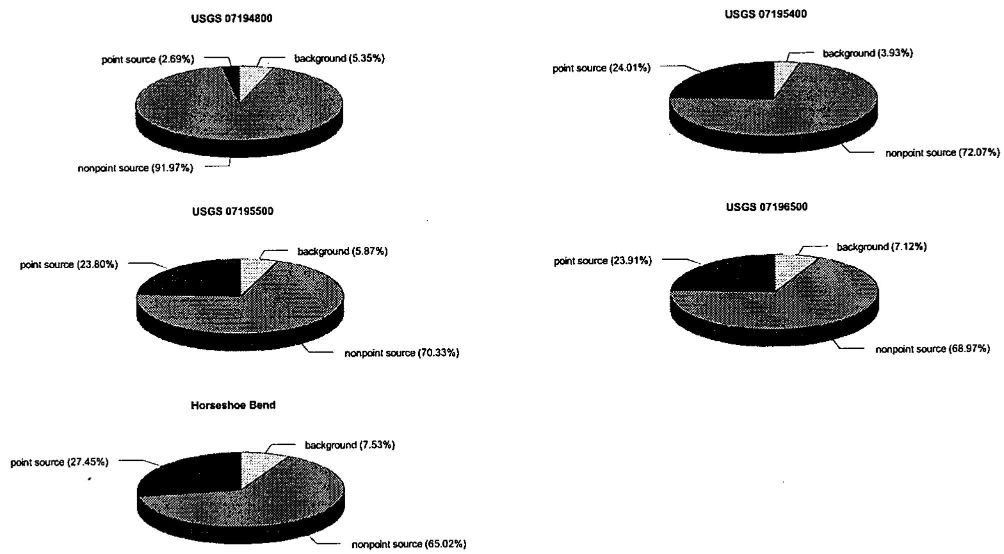

Figure 38. Estimates of Contributions of Nonpoint, Point, and Background Sources to Total Phosphorus Load at Mainstem USGS Gaging Stations and Horseshoe Bend Under Average Annual Conditions.

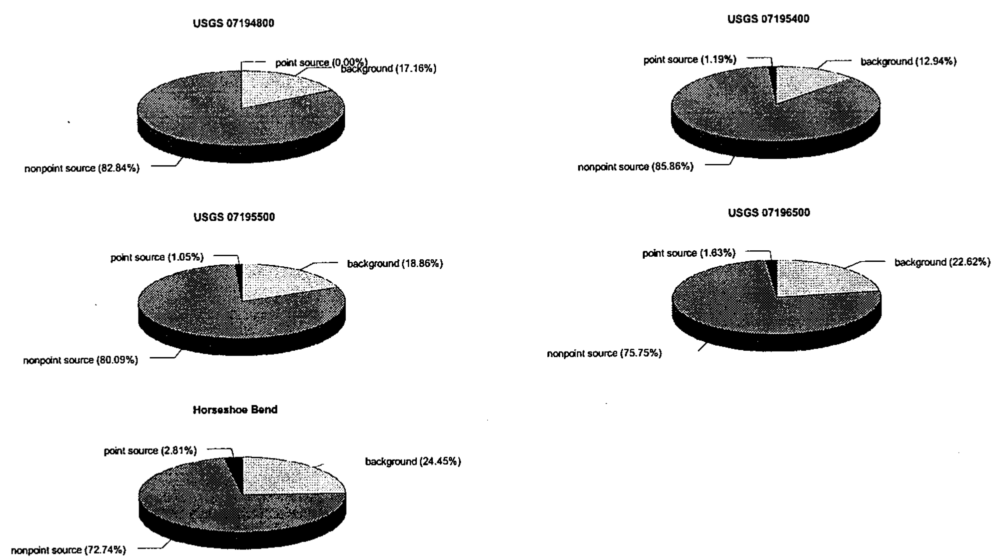

Figure 39. Contributions of Nonpoint, Point, and Background Sources to Total Nitrogen Load at Mainstem USGS Gaging Stations and Horseshoe Bend Under Average Annual Conditions.

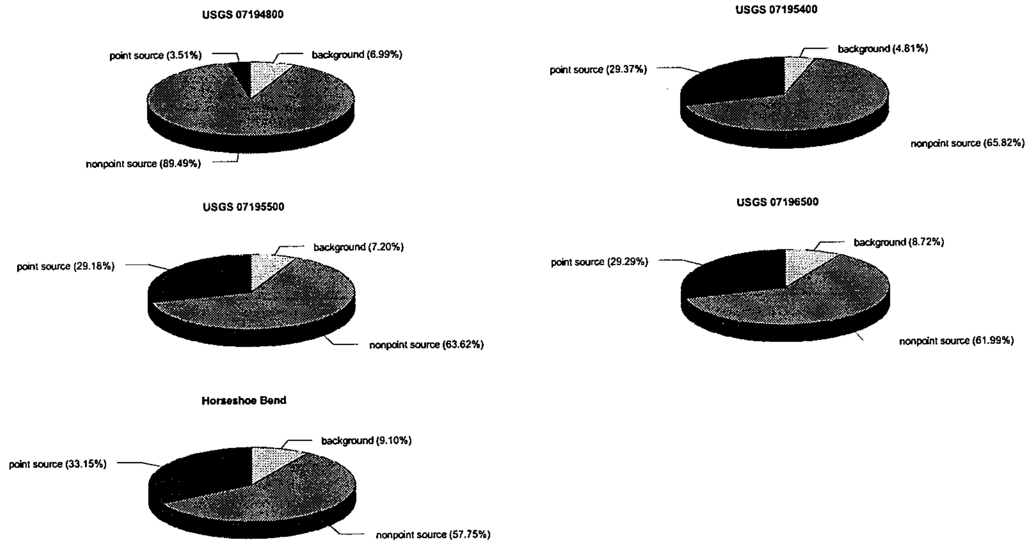

Figure 40. Estimates of Contributions of Point, Nonpoint, and Background Sources to Total Phosphorus Loads at Mainstem USGS Gaging Stations and Horseshoe Bend with a 25% Reduction of Nonpoint Source Inputs.

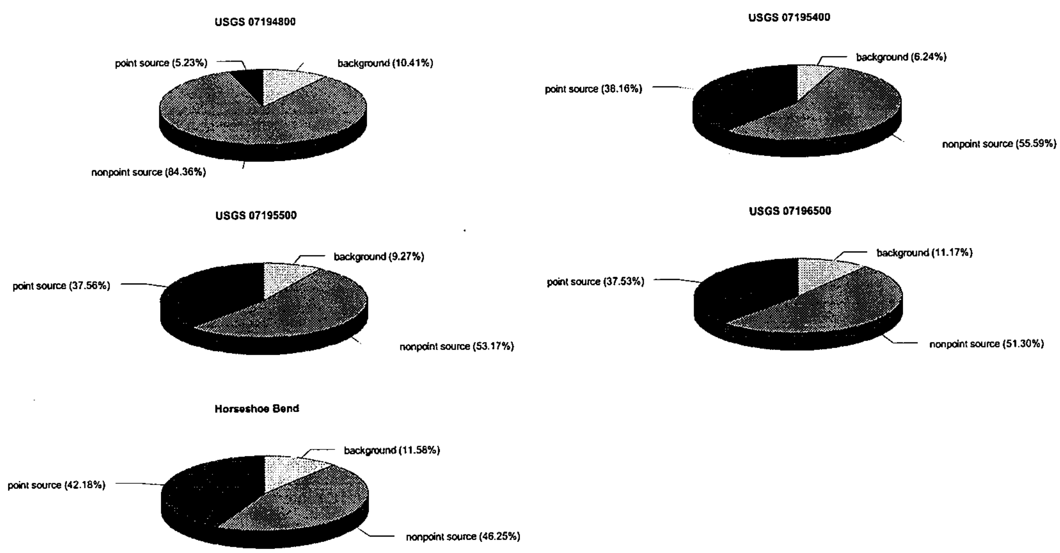

Figure 41. Estimates of Contributions of Point, Nonpoint, and Background Sources to Total Phosphorus Loads at Mainstem USGS Gaging Stations and Horseshoe Bend with a 50% Reduction of Nonpoint Source Inputs.

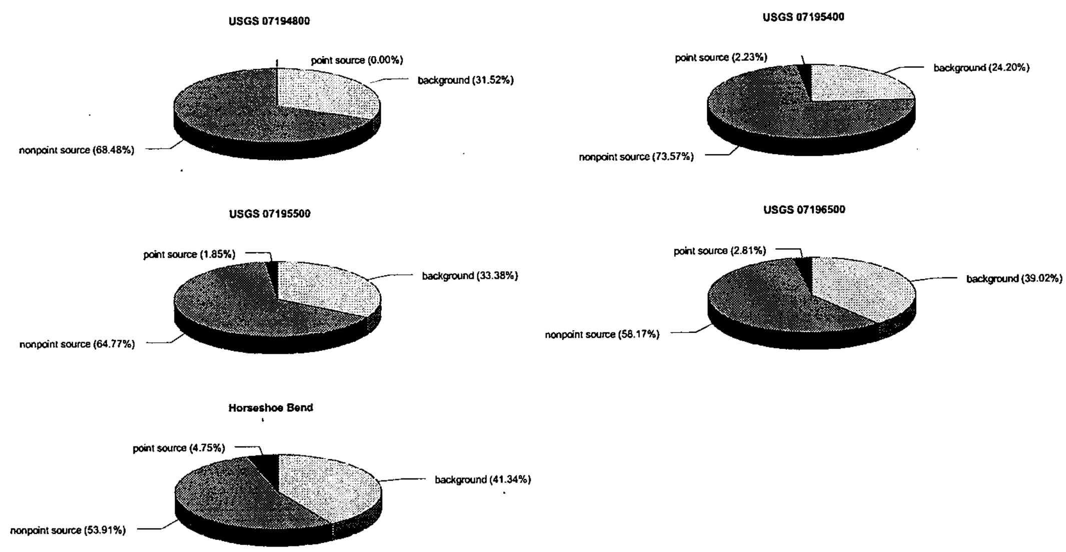

Figure 42. Estimates of Contributions of Point, Nonpoint, and Background Sources to Total Nitrogen Loads at Mainstem USGS Gaging Stations and Horseshoe Bend with a 50% Reduction of Nonpoint Source Inputs.

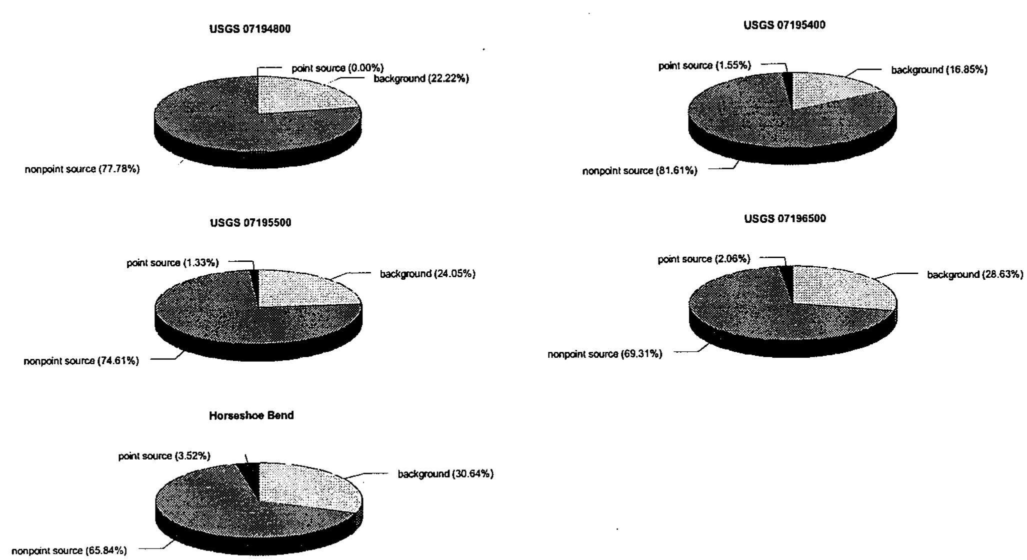

Figure 43. Estimates of Contributions of Point, Nonpoint, and Background Sources to Total Nitrogen Loads at Mainstem USGS Gaging Stations and Horseshoe Bend with a 25% Reduction of Nonpoint Source Inputs.

Vollenweider (1976, in Wetzel, 1983) and others have attempted to relate phosphorus loading in freshwater lakes to lake trophic status. Lakes with mean total phosphorus concentrations around 0.01 mg/l would be classified as oligotrophic, and concentrations around 0.1 mg/l would lead to a classification of potentially eutrophic. The critical concentrations vary with respect to hydraulic residence time and mean lake depth. Lakes with larger volumes and shorter residence times are be able to assimilate greater phosphorus loads without showing the effects of eutrophication. Based on the table of suggested loadings given earlier in the section on phosphorus (Table II), distributions of simulated total phosphorus loads under annual average, 25% and 50% reduction of nonpoint sources were plotted using Lake Tenkiller's mean depth and hydraulic residence time (Figure 44). All cases, including the absence of all nonpoint source loadings, would suggest that enough phosphorus in entering Lake Tenkiller to exacerbate eutrophic conditions. It is important to note that the relationship was developed for natural lakes and that reservoirs tend to act differently in that they have riverine attributes in the upper portions (Thornton, et al., 1990).

Wetzel (1983) developed a similar relationship for total nitrogen based on the work of Vollenweider and others. Using a similar graphing technique, Figure 45 depicts the results of total nitrogen loading to lake Tenkiller under simulated annual average, 25% reduction of NPS, and a 50% reduction of NPS. Again, all cases would suggest that total nitrogen loading to Lake Tenkiller is excessive.

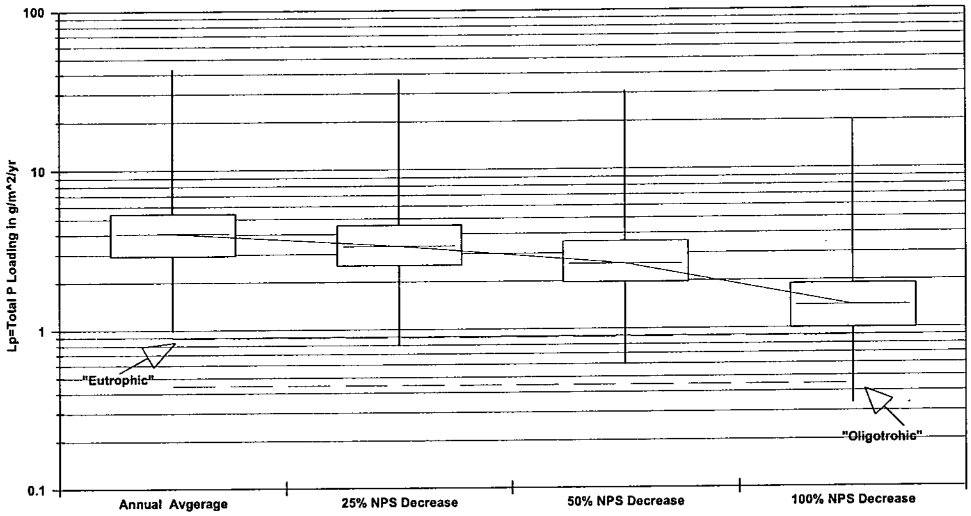

Figure 44. Simulated Distributions of Total Phosphorus Loading at Horseshoe Bend Plotted Against Vollenweider's (1976) Trophic Classification Model.

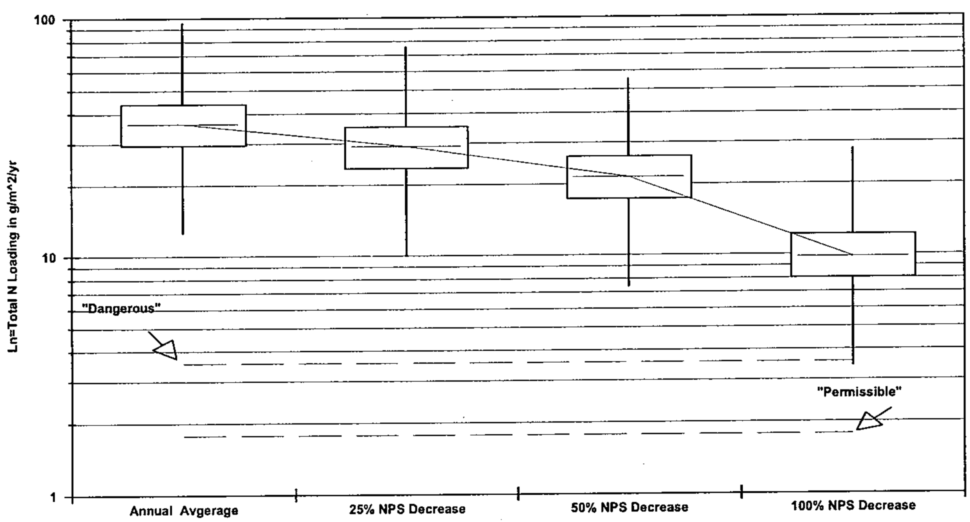

Figure 45. Simulated Distributions of Total Nitrogen Loading at Horseshoe Bend Plotted Against Wetzel (1983) Trophic Classification Model.

Carlson (1977) developed a numerical trophic state index for lakes that ranges from 0 to 100 where each major division (10, 20, 30, etc.) represents a potential doubling in algal biomass. There are no set delineations describing oligo-, meso-, or eutrophic conditions, rather the index describes a trophic continuum. Based solely on total phosphorus loading to Lake Tenkiller, Table LXXIII shows the results of using this index. The median annual average simulated total phosphorus load corresponding to an index number of 81 would suggest that Lake Tenkiller would be experiencing loading sufficient to result in eutrophic conditions. Decreases in nonpoint source total phosphorus loads result in decreases in the index number. A 100% reduction of nonpoint sources of phosphorus would bring the lake closer to a mesotrophic classification.

TABLE LXXIII

CARLSON'S TROPHIC STATE INDEX RESULTS FOR LAKE TENKILLER
(BASED ON ESTIMATED TOTAL PHOSPHORUS CONCENTRATION)

	Annual Average	25% Nonpoint Source Reduction	50% Nonpoint Source Reduction	100% Nonpoint Source Reduction
Minimum	61	57	53	45
25% Percentile	76	74	71	61
50% Percentile	81	78	74	65
75% Percentile	85	83	79	70
Maximum	115	113	110	104

Control of pollutants of agricultural origin presently focuses on their sources. A combination of methodologies collectively known as Best Management Practices (BMPs) is expected to reduce the amount of potential pollutant applied to the land and the amount of pollutant entering streams and ground water. These practices include controlling erosion and drainage, conscientious crop management, prudent management of animals and associated pasture and rangeland, conservative utilization of nutrients, and precise methods for controlling pests. BMPs are expected to be adapted to specific site conditions rather than applied across the board. This requires close cooperation between the land manager who will implement the BMPs and the "experts" who will help to decide on the set of practices which should provide the most advantageous result.

General erosion and sediment control practices would include conservation tillage, contour farming, critical area planting, crop residue use, perennial vegetation at field borders, vegetated filter strips within fields, grassed waterways, water and sediment control basins, terracing, and riparian zone protection.

Some practices generally applicable include: 1) agricultural BMPs which reduce erosion and runoff; 2) efficient use of irrigation to minimize leaching of nitrate from the root zone before plant uptake can occur; 3) consideration of cropping sequences or cover crops that might utilize residual nutrients; 4) improved fertilizer management (timing, rates, and evaluation of soil nitrogen and phosphorus availability); 5) use of slow release N and P fertilizers for long-season crops; and, 6) use of nitrification and urease inhibitors where appropriate.

Management practices specifically designed to reduce nutrient export from land surfaces to be considered would include:

1) the use of soil surveys in determining soil productivity and

identifying environmentally sensitive sites and areas;

2) the use of producer documented yield histories to determine realistic yield expectations;

3) the use of soil testing for pH, phosphorus, and nitrogen;

4) testing manures and compost for nutrient content;

5) the use of proper timing, formulation, and application rates of fertilizers to maximize plant utilization while minimizing loss to the environment; and,

6) the use of buffer areas.

Grazing management practices, with regard to potential effects of animals grazing near streams, consider excluding animals from critical streambank areas and by providing stream crossings and/or hardened or alternative water access. Additionally, overgrazing of pasture and rangelands should be minimized to reduce degradation of vegetative cover and aid in the reduction of erosion and sediment loss.

Thoughtful selection of applicable BPMs, selectively applied first to those subbasins delivering the greatest nutrient loads, and best available technologies to reduce nutrient loads from point sources, would seem necessary to prolong the life of Lake Tenkiller.

The poultry industry is economically important to the region and it would be necessary to work with members of the industry to implement strategies which reduce nutrient loading but do not inhibit the growth and expansion of this industry. Methods for exporting animal wastes out of the basin in the form of composted fertilizer product should be vigorously investigated and pursued. Poultry farmers in the region who produce more litter than they can responsibly apply to pasture and range lands on their property might consider selling the litter to other landowners in the region who have a need for a good fertilizer product. State agencies should also consider creating avenues for distributing the litter on an even wider scale to allow for removal of significant quantities of the litter out of the watershed.

As indicated in the graphics depicting sources of nutrients reaching Lake Tenkiller, point sources of phosphorus are not insignificant. In the analysis of historical water quality data, point source discharges were reduced over distance traveled to Lake Tenkiller using first-order kinetic assimilation coefficients. These coefficients were calculated based on available water quality data near the mid-point of the modeled system, and were assumed to represent the entire system. Point source discharges, such as that of the City of Fayetteville, traveling close to 160 kilometers to the lake, were shown contribute minimally to total phosphorus load. In the simulations, point source discharges were reduced at calculated rates only until they were input into the modeled system. This resulted in showing the simulated point source total phosphorus load reaching Horseshoe Bend (79,800 kg/yr) as being only slightly less (14%) than the sum of total phosphorus loads from each of the point sources (92,600 kg/yr).

As explained by Newbold (in Calow and Petts, 1992), biota remove nutrients from the water, but also regenerate nutrient to the water. The cycling of nutrients in a river may be intensive and still produce negligible effects on nutrient concentrations. For phosphorus, which does not exchange with the atmosphere, biota cannot alter the log-run total transport substantially. Biota can influence chemical and physical forms of nutrients, and thus the timing of nutrient transport.

Allen (1995) discusses evidence that variations in discharge on seasonal and annual time scales influence whether nutrients are stored or exported. Allen discusses a phosphorus budget study by Meyers and Likens (1979) which estimated that 48% of annual inputs and 67% of exports of nutrients occurred during 10 days of the water year. Phosphorus accumulated in stream sediments and biota for 319 days of the year of study. In years of low flow, Meyer and Likens reported exports of phosphorus to be less than imports with export/import ratios as low as 0.6. In years of high flow the reverse occurred with export/import ratios as high as 1.5.

Different areas of a system may act differently in the rates with which nutrients are incorporated into biota and settle. Smaller streams may act as more efficient buffers to the transport of nutrients downstream, while larger riverine systems may simply act as through-put systems (Allen, 1995). In the long-term, small amounts of nutrients may be removed from the system, but would be transported downstream in pulses corresponding to flood events which would scour bottom sediments and organisms and transport them some distance downstream before they again settle to the bottom. Some nutrients would settle in flood plains and perhaps be effectively removed from the water system, but most would likely eventually reach a downstream reservoir. Modeling the river system as steady-state may not offer the ability to accurately account for this complex and dynamic process.

In light of the previous discussion, it seems necessary to include some simple information regarding the total quantity of nutrients being input into the system. Using average annual total background loads as calculated with the U.S. EPA screening methods (Mills et al., 1985), a sum of estimated average annual point source loads at the source, average annual nonpoint source total phosphorus as estimated by SIMPLE, average annual total nitrogen loads estimated using unit-area loading methods, and QUAL2EU modeling results of average annual loads of these nutrient at the Horseshoe Bend Area of Lake Tenkiller, a simple calculation was made to estimate the amounts of each nutrient being assimilated by the system. Table LXXIV shows the results of this calculation. If nutrients are not removed from the system by settling and biotic uptake, and are eventually transported downstream to Lake Tenkiller, then the estimated average annual loads of total phosphorus and total nitrogen are 322,300 and 2,820,000 kg/yr, respectively. These values are 31,300 and 340,000 kg/yr, respectively, higher than modeled annual averages and represent assimilated nutrients. In terms of total inputs to the QUAL2EU model, employing first-order kinetic assimilation rates results in a reduction of total phosphorus from 103,300 kg/yr at the source to 82,000 kg/yr where input into the model. This accounts for about 67% all total assimilation of total phosphorus. The QUAL2EU model reduces the total phosphorus load by only 10,000 kg/yr for the remainder of the flow distance from the point source input point down to Lake

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Tenkiller. Thus, the developed assimilation rates, and the settling coefficients for QUAL2EU, would seem to differ significantly. If we assume that all phosphorus input into the system moves down to the reservoir, then point source contributions to total phosphorus load increases to 32% from the 27.5% based on QUAL2EU results. For nitrogen, the point sources represent a small fraction of total inputs and no significant change in relative contribution is seen.

TABLE LXXIV

ESTIMATES OF TOTAL AVERAGE ANNUAL LOADS OF PHOSPHORUS AND NITROGEN ENTERING THE ILLINOIS RIVER BASIN ABOVE THE HORSESHOE BEND AREA OF LAKE TENKILLER INCLUDING SOURCES AND SINKS

Total Inputs by Source	Estimated Average Annual Total Phosphorus Load (kg/yr)	Estimated Average Annual Total Nitrogen Load (kg/yr)
a) Background	25,000 (7.8 %)	610,000 (21.6%)
b) Point Source	103,300 (32.0%)	70,000 (2.5%)
c) Nonpoint Source	194,000 (60.2%)	2,140,000 (75.9%)
d) Total	322,300 (100%)	2,820,000 (100%)
QUAL2EU Estimates at Horseshoe Bend		
e) Background	21,900	605,000
f) Point Source	79,800	69,500
g) Nonpoint Source	189,000	1,800,000
h) Total	291,000	2,480,000
i) QUAL2EU Point Source Input After Application of First-Order Assimilation Rate	82,000 79% of Total Point Source (b)	60,200 86% of Total Point Source (b)
j) Point Source Assimilation Before QUAL2EU (b - i)	21,300 6.6% of Total (d)	9,800 0.3%of Total (d)
Assimilation in QUAL2EU (d - h - j)	10,000 3.1% of Total (d)	330,200 11.7% of Total (d)
Total Assimilation (d-h)	31,300 9.7% of Total (d)	340,000 12.1% of Total (d)

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

Based on the information available, we can draw several conclusions in regard to nutrient transport in the Illinois River Basin. First, there has been a dramatic increase in the number of poultry houses in the basin since 1980. The birds raised in these houses produce significant quantities of manure, the bulk of which is applied to pasture and rangeland within the basin. The automatic samplers gathered limited information with respect to the typical runoff concentration at only two points in the basin. However, the results were what would be expected. During runoff events there is an increase in nutrient concentration which would correspond to surface nutrients carried to the stream in either dissolved or sediment bound forms. Ultimately these nutrients reach the lower portion of the basin at Lake Tenkiller.

Historical water quality and discharge analysis suggest that there are increasing trends at some locations with regard to phosphorus concentration and load, and more evident increasing trends with regard to nitrogen concentration and load. The discharge and concentration data combined suggest that a great majority of the nutrient load carried to the Illinois River and its tributaries occurs during "high" flows, again suggesting that these nutrients are mobilized during runoff events.

Data constructed for use with the SIMPLE model used the locations of poultry houses to estimate soil phosphorus distributions in pasture lands. Runoff, calculated from rainfall data, then transports a portion of the nutrients in the soil to the river and its tributaries. Subbasins with the greatest densities of poultry houses, and hence high estimated soil phosphorus levels, generally delivered the greatest quantities of nutrients to the Illinois River and its tributaries.

These estimates of nutrient loading, when routed through the riverine model QUAL2EU, closely approximate the nutrient loading at the Horseshoe Bend area of Lake Tenkiller based on historical data. Estimates of point and background nutrient loading in the basin allowed for approximations of the distribution of the total nutrient load between nonpoint, point, and background sources. Nonpoint sources account for the majority of nutrient loading. Point source nutrient loading is also significant, especially for phosphorus.

Finally, models of lake trophic status suggest that the average annual loading of both phosphorus and nitrogen at the Horseshoe Bend area of Lake Tenkiller is excessive and will likely lead to a continued deterioration of lake water quality. In fact, even with 25%, 50%, and 100% reductions of nonpoint source nutrient loading, the lake would still be receiving loads of phosphorus and nitrogen which would exacerbate the eutrophic characteristics already documented.

The modeling study performed on the Illinois River Basin, utilizing GIS for estimation of nutrient export in combination with a stream routing model, provides results which can be used to develop management strategies for the reduction of nutrient loading to Lake Tenkiller. Critical areas can be identified which would be obvious starting points to mitigate nutrient export from the basin. The stream routing portion of the modeling scheme allowed for the estimation of annual contributions of nutrients from various sources and can be employed to determine the effectiveness of various management strategies applied.

This study did not test the effectiveness of specific management strategies but rather the effects of specified reductions in nonpoint nutrient loading. The modeling scheme could be easily modified to test the effects of certain specific management practices. The SIMPLE model can provide estimates of nutrient export under specific management schemes which would be accounted for in the land use/land cover data layer and associated parameters, as well as alterations in the ways fertilizer is applied to fields, and the initial levels of phosphorus in fields related to land use.

There are areas where model confidence could be enhanced. The initial phosphorus data layer for the study was based on county or watershed level soil testing data which may not be accurate. A more representative soil testing technique using samples from each of the various land uses weighted by the areal extent of each land use may provide a more accurate picture of present initial phosphorus levels.

The digital elevation data for the basin was not all at the most desirable resolution of 30 meters. The use of 80 meter resolution data in a significant portion of the Arkansas (seven 7.5 minute quadrangles) part of the Illinois River Basin affected the output of the digital terrain model in that area. Since this portion of the basin is generally more topographically uniform, certain areas may not be modeled as accurately as those with 30 meter resolution data.

The land use/land cover data used in this study was from 1985. The use of more recent information via satellite imagery or some other more current source would be valuable. Confined animal sites were also obtained from this 1985 data and have likely changed significantly over the last decade. More current information in these areas would lead to greater confidence in the results of the modeling scheme.

While the focus of many nonpoint nutrient studies focus on phosphorus, information on nitrogen loading is useful and important in considerations of lake management. Nitrogen loading values in this study were based on unit loading assumptions. The SIMPLE model does not model the export of nitrogen. A more refined technique for accounting for nitrogen would enhance these results.

The riverine model could be expanded to travel further up the Illinois River and its tributaries to more accurately model both point and nonpoint nutrient inputs. This would allow for a more precise modeling of nutrient input to specific points within the basin. Obtaining more basin specific parameters in terms of hydrologic characteristics and nutrient and algal reaction coefficients would improve confidence in modeled predictions.

The sources of nutrients were divided into point (municipalities), nonpoint, and background. The nutrient loads determined to be of nonpoint origin could be further evaluated to include other sources. A survey of septic systems in the basin and approximations of the nutrient contribution from them could be valuable. Range cattle were essentially disregarded in the modeling effort and some estimates of the impact of these animals on the system should be included.

Overall, the modeled system corresponds reasonably well with observed historical data. It can be an effective tool in analyzing the dynamics of nutrient transport in a large watershed, and it can provide useful information for directing management schemes to improve water quality.

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APPENDIX A

DEVELOPMENT OF DISCHARGE COEFFICIENTS FOR THE QUAL2EU MODEL

The QUAL2EU model offers two options for describing the hydraulic characteristics of the system, a geometric representation and a functional representation. Data were readily available to determine discharge coefficients for the functional representation. The USGS ADAPS Database offers access to stage-discharge rating tables for gaging stations, and also to discharge measurement data. Stage-discharge rating tables with depth and discharge data were available for each of the eight gaging stations in the basin. Discharge measurement data, also available at all eight gaging stations, which includes periodic observations of stream velocity and discharge, among other parameters, were downloaded for WTRs 1980 - 1993.

Regression was used to solve :

$$\bar{\ } = aQ^{b}$$

and

$$d = \alpha Q^{\beta}$$

for a, b, α, and ,, the empirical constants. Tables LXXV and LXXVI include the coefficients developed for each of the eight gaging stations in the Illinois River Basin. Reaches in the developed QUAL2EU model of the Illinois River, and its tributaries, which did not have a USGS gaging station at their starting location, were assigned interpolated velocity and discharge coefficients based on coefficients determined for gaging stations above and/or below the reach.

TABLE LXXV

COEFFICIENTS FOR VELOCITY DEVELOPED FOR
USGS GAGING STATIONS IN THE
ILLINOIS RIVER BASIN

USGS Gaging Station Identification	Coefficient for Velocity (*a*)	Exponent for Velocity (*b*)	Velocity/ Discharge Observations (n)	Velocity/ Discharge r^2
07194800	0.248	0.338	28	0.73
07195400	0.375	0.140	26	0.19
07195500	0.269	0.248	27	0.46
07196500	0.148	0.286	36	0.58
07195000	0.283	0.499	52	0.68
07196000	0.371	0.276	35	0.68
07196900	0.313	0.291	56	0.79
07197000	0.306	0.316	39	0.60

TABLE LXXVI

COEFFICIENTS FOR DEPTH DEVELOPED FOR
USGS GAGING STATIONS IN THE
ILLINOIS RIVER BASIN

USGS Gaging Station Identification	Coefficient for Depth (α)	Exponent for Depth ( )	Depth/ Discharge Observations (n)	Depth/ Discharge r^2
07194800	0.203	0.558	34	0.99
07195400	0.255	0.481	19	0.99
07195500	0.123	0.634	20	0.99
07196500	0.122	0.561	18	0.99
07195000	0.102	0.793	21	0.98
07196000	0.120	0.468	19	0.98
07196900	0.227	0.456	29	0.99
07197000	0.132	0.587	26	0.99

APPENDIX B

QUAL2EU MODEL CALIBRATION

TECHNIQUES AND RESULTS

The QUAL2EU model, designed to simulate phosphorus and nitrogen transport from the Illinois River Basin down to the Horseshoe Bend Area of Lake Tenkiller, was designed to accommodate SIMPLE outputs from the various subbasins comprising the basin as a whole. The model was then calibrated using water quality data (water years 1980 - 1993) from USGS gaging stations and scenic river stations within the basin. Mean annual statistics were calculated for discharge, dissolved, organic and total phosphorus, and for organic nitrogen, ammonia, nitrate + nitrite, and total nitrogen. The calculated mean annual values were incorporated into the QUAL2EU model as initial conditions at sites in the model corresponding to the water quality monitoring sites. Mean annual discharges were used at each of the four headwater locations, and gaging station data not at headwater locations were used to calibrate flow proceeding down toward the lake. Model runs were performed until average predicted nutrient concentrations at monitoring stations were within 15% of historical annual average concentrations.

Previous experience with the QUAL2E model has shown that accurate hydrologic characteristics are necessary for the model. USGS ADAPS data available for each of the gaging stations was used to calculated coefficients of depth and velocity at each station. Rating tables at each station were used to calculate coefficients of depth. Also available for each station were station reports with velocity measurements recorded with discharge.

Table LXXVII lists statistical summaries of nutrient water quality data for scenic river monitoring sites in the Illinois River Basin. Table LXXVIII lists final

QUAL2EU reaction coefficients and information on sources. Figures 56 - 67 compare simulated discharge and water quality to historical means at USGS gaging stations and scenic river sites.

TABLE LXXVII

STATISTICAL SUMMARIES OF NUTRIENT DATA AT SCENIC RIVER MONITORING SITES IN THE ILLINOIS RIVER BASIN FOR WATER YEARS 1980 - 1993

Station	Statistic	Total Nitrogen (mg/l)	Ammonia (mg/l)	Total Kjeldahl Nitrogen (mg/l)	Nitrate + Nitrite (mg/l)	Total Phosphorus (mg/l)	Ortho-Phosphate as P (mg/l)
SR1	Mean	2.3	0.3	0.5	1.9	0.33	0.16
	Standard Deviation	1.1	0.4	0.3	0.9	0.40	0.12
	Count	116	5	121	121	121	64
SR2	Mean	2.0	0.1	0.4	1.7	0.24	0.13
	Standard Deviation	1.4	0.1	0.3	1.2	0.22	0.10
	Count	115	22	134	134	137	80
SR3	Mean	1.8	0.1	0.4	1.5	0.23	0.14
	Standard Deviation	1.0	0.1	0.3	0.8	0.18	0.12
	Count	107	29	133	133	136	79
SR4	Mean	1.8	0.1	0.4	1.5	0.21	0.13
	Standard Deviation	1.0	0.1	0.4	0.8	0.18	0.12
	Count	107	28	133	133	135	78
SR4.5	Mean	---	0.1	0.4	1.3	0.19	0.12
	Standard Deviation	---	0.1	0.2	0.7	0.09	0.07
	Count	0	30	27	27	30	29
SR5	Mean	1.8	0.1	0.5	1.4	0.19	0.10
	Standard Deviation	1.2	0.1	0.6	0.8	0.26	0.10
	Count	117	27	142	142	144	87

TABLE LXXVIII

REACTION COEFFICIENTS USED IN THE QUAL2EU MODEL OF THE ILLINOIS RIVER BASIN

Parameter	Units	Value	Source
Ratio of chlorophyll *a* to Algal biomass	μg Chl *a*/mg A	10	U.S. EPA (1991b)
Fraction of algal biomass that is nitrogen	mg N/mg A	0.08	Bowie et al. (1985), U.S. EPA (1991b)
Fraction of algal biomass that is phosphorus	mg P/mg A	0.011	Bowie et al. (1985), U.S. EPA (1991b)
Maximum algal growth rate	day^{-1}	2.5	Bowie et al. (1985), U.S. EPA (1991b)
Algal respiration rate	day^{-1}	0.15	U.S. EPA (1991b)
Michaelis-Menton half-saturation constant for nitrogen	mg N/l	0.03	U.S. EPA (1991b)
Michaelis-Menton half-saturation constant for phosphorus	mg P/l	0.005	U.S. EPA (1991b)
Non-algal light extinction coefficient	ft^{-1}	0.3	
Linear algal self-shading coefficient	$ft^{-1}/((\mu g\ Chl\ a)/l)$	0.043 2	U.S. EPA (1991b)
Nonlinear algal self-shading coefficient	$ft^{-1}/(\lambda g\ Chl\ a/l)^{2/3}$	0.003	U.S. EPA (1991b)
Algal preference for ammonia		0.7	U.S. EPA (1991b)
Algal settling rate	ft/day	0.5	Bowie et al. (1985), U.S. EPA (1991b)
Benthos source rate for dissolved phosphorus	mg P/ft^2-day	0	U.S. EPA (1991b)
Benthos source rate for ammonia	mg O/ft^2-day	0	U.S. EPA (1991b)

TABLE LXXVIII

REACTION COEFFICIENTS USED IN THE QUAL2EU MODEL OF THE ILLINOIS RIVER BASIN

Parameter	Units	Value	Source
Organic nitrogen settling rate	day^{-1}	0.01	Bowie et al. (1985), U.S. EPA (1991b)
Organic phosphorus settling rate	day^{-1}	0.01	Bowie et al. (1985), U.S. EPA (1991b)
Rate constant for biological oxidation of ammonia to nitrite	day^{-1}	0.2	Bowie et al. (1985), U.S. EPA (1991b)
Rate constant for biological oxidation of nitrite to nitrate	day^{-1}	2.0	Bowie et al. (1985), U.S. EPA (1991b)
Rate constant for hydrolysis of organic nitrogen to ammonia	day^{-1}	0.01	Bowie et al. (1985)
Rate constant for decay of organic phosphorus to dissolved phosphorus	day^{-1}	0.1	Bowie et al. (1985), U.S. EPA (1991b)

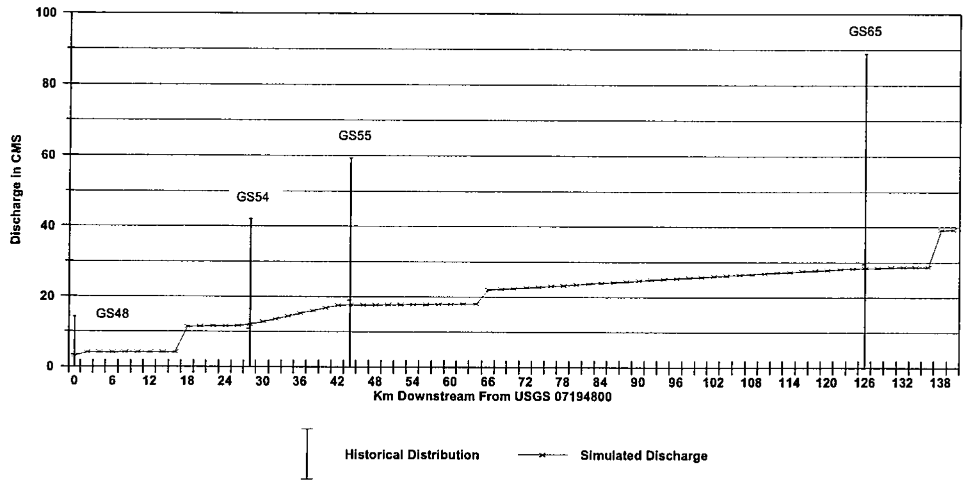

Figure 46. Results of Calibration of QUAL2EU Model with Historical Discharge at Mainstem Stations on the Illinois River. Historical Data (WTRs 1980 - 1993) is Shown as the Mean Plus and Minus One Standard Deviation.

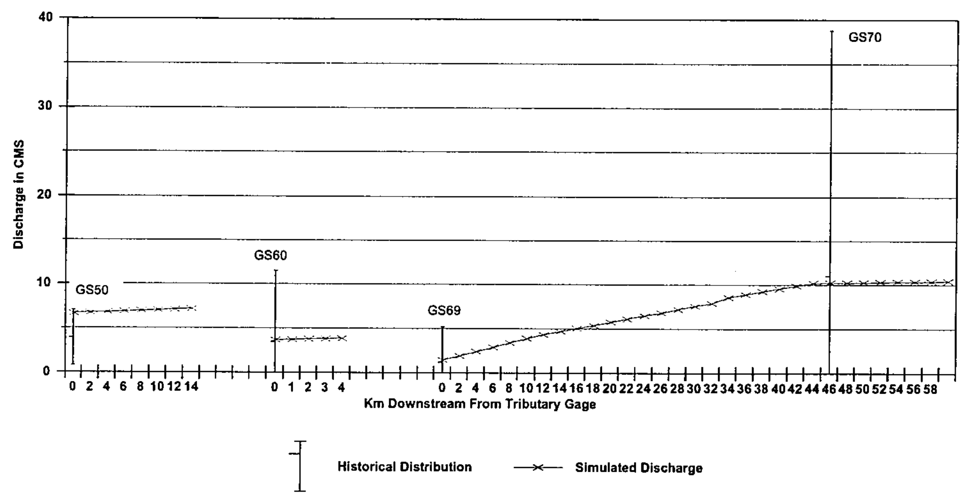

Figure 47. Results of Calibration of QUAL2EU Model with Historical Discharge at Tributary Stations in the Illinois River Basin. Historical Data (WTRs 1980 - 1993) is Shown as the Mean Plus and Minus One Standard Deviation.

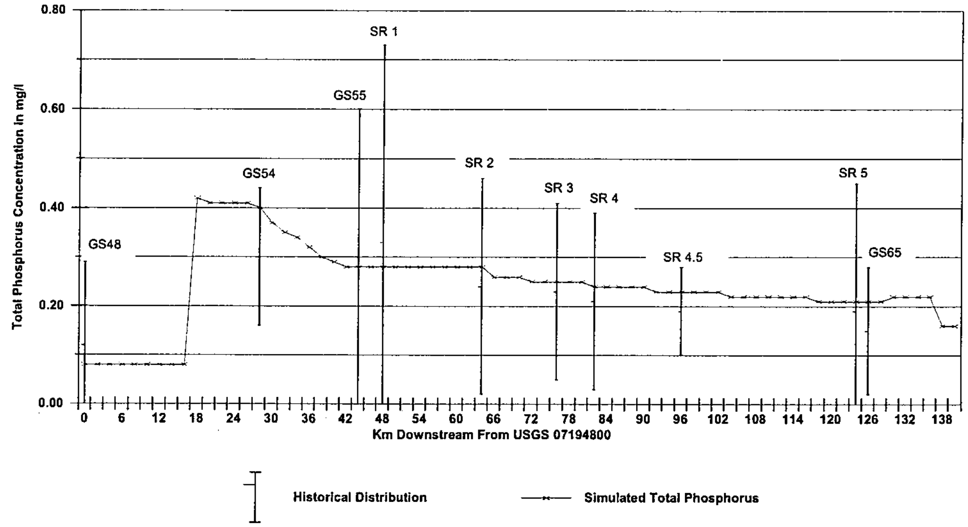

Figure 48. Results of Calibration of QUAL2EU Model with Historical Total Phosphorus Data at Mainstem USGS and Water Quality Monitoring Stations. Historical Data (WTRs 1980 - 1993) is Shown as the Mean Plus and Minus One Standard Deviation.

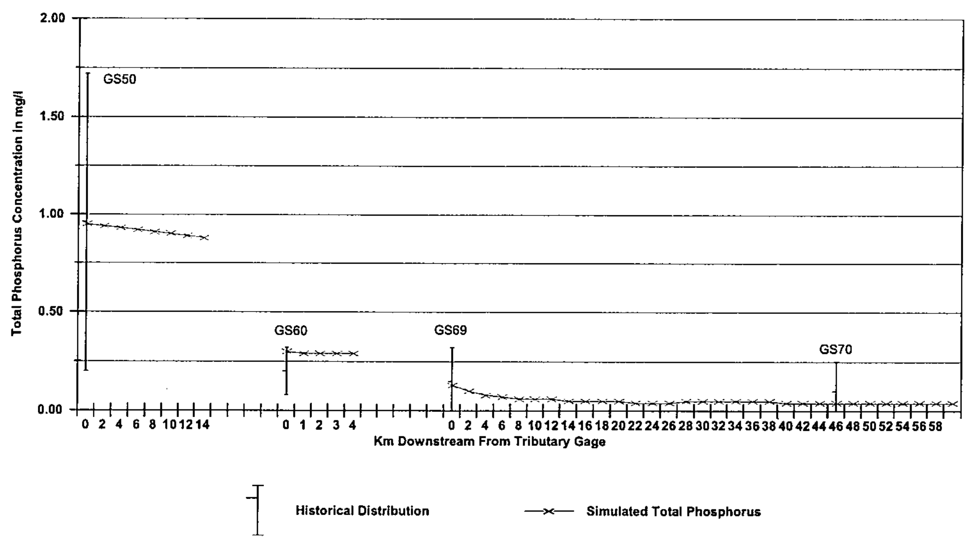

Figure 49. Results of Calibration of QUAL2EU Model with Historical Total Phosphorus Data at Tributary Stations in the Illinois River Basin. Historical Data (WTRs 1980 - 1993) is Shown as the Mean Plus and Minus One Standard Deviation.

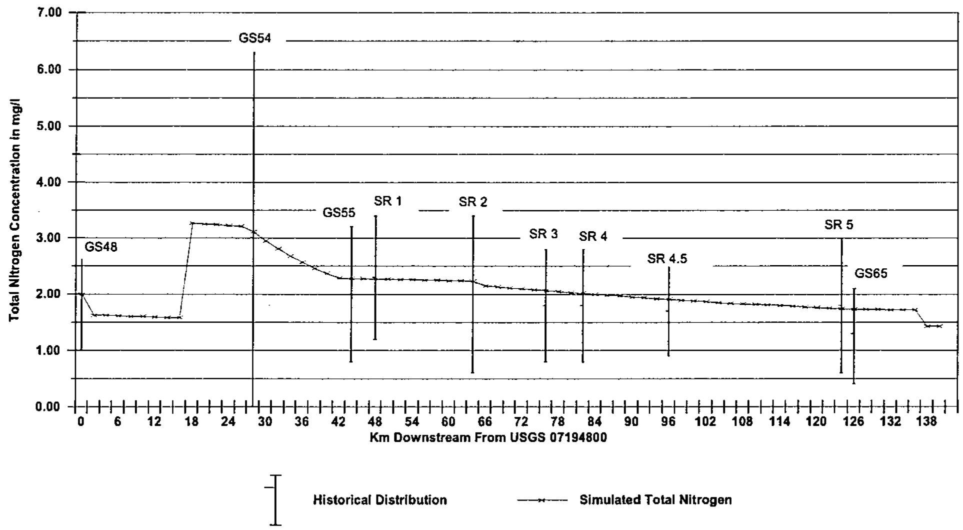

Figure 50. Results of Calibration of QUAL2EU Model with Historical Total Nitrogen Data at Mainstem Stations on the Illinois River. Historical Data (WTRs 1980 - 1993) is Shown as the Mean Plus and Minus One Standard Deviation.

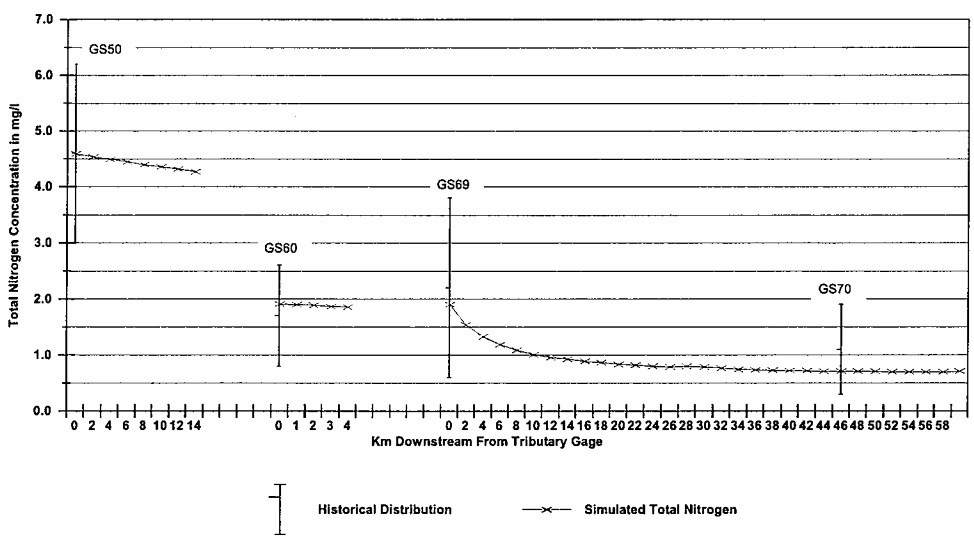

Figure 51. Results of Calibration of QUAL2EU Model with Historical Total Nitrogen Data at Tributary Stations in the Illinois River Basin. Historical Data (WTRs 1980 - 1993) is Shown as the Mean Plus and Minus One Standard Deviation.

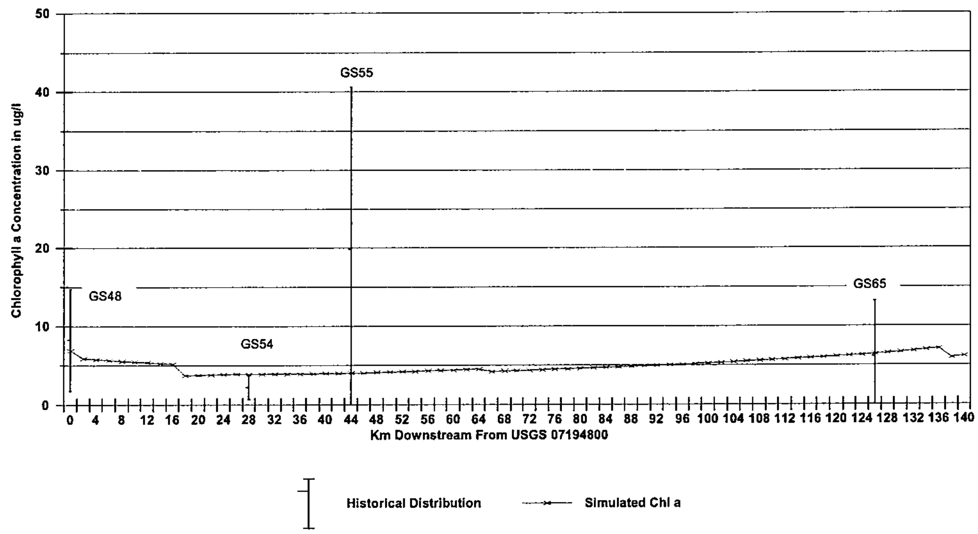

Figure 52. Results of Calibration of QUAL2EU Model with Historical Chlorophyll *a* Data at Mainstem Stations on the Illinois River. Historical Data (WTRs 1980 - 1993) is Shown as the Mean Plus and Minus One Standard Deviation.

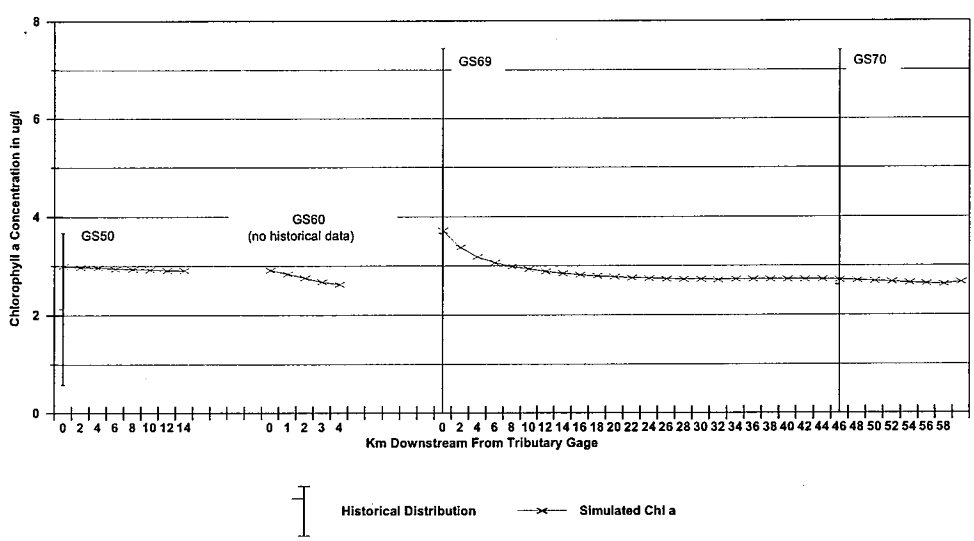

Figure 53. Results of Calibration of QUAL2EU Model with Historical Chlorophyll *a* Data at Tributary Stations in the Illinois River Basin. Historical Data (WTRs 1980 - 1993) is Shown as the Mean Plus and Minus One Standard Deviation.

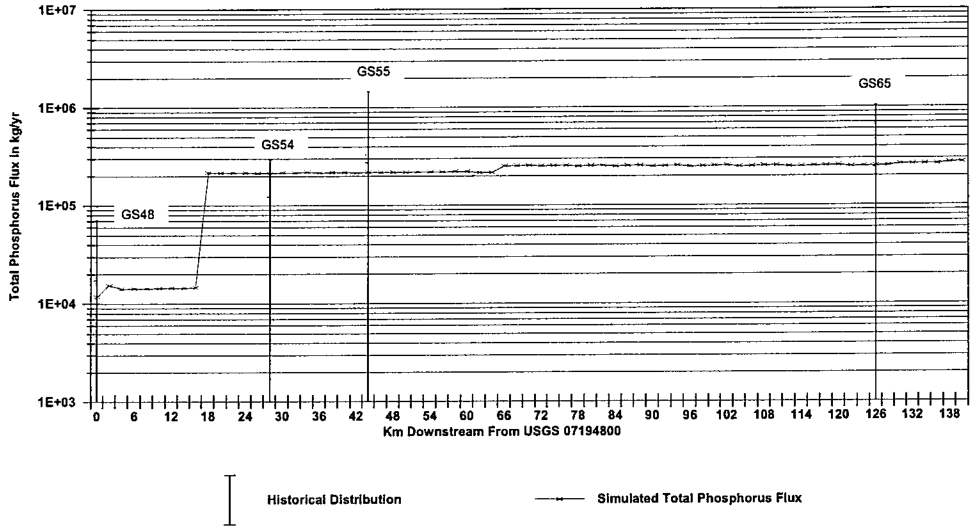

Figure 54. Results of Calibration of QUAL2EU Model with Historical Total Phosphorus Loading Data at Mainstem Stations on the Illinois River. Historical Data (WTRs 1980 - 1993) is Shown as the Mean Plus and Minus One Standard Deviation.

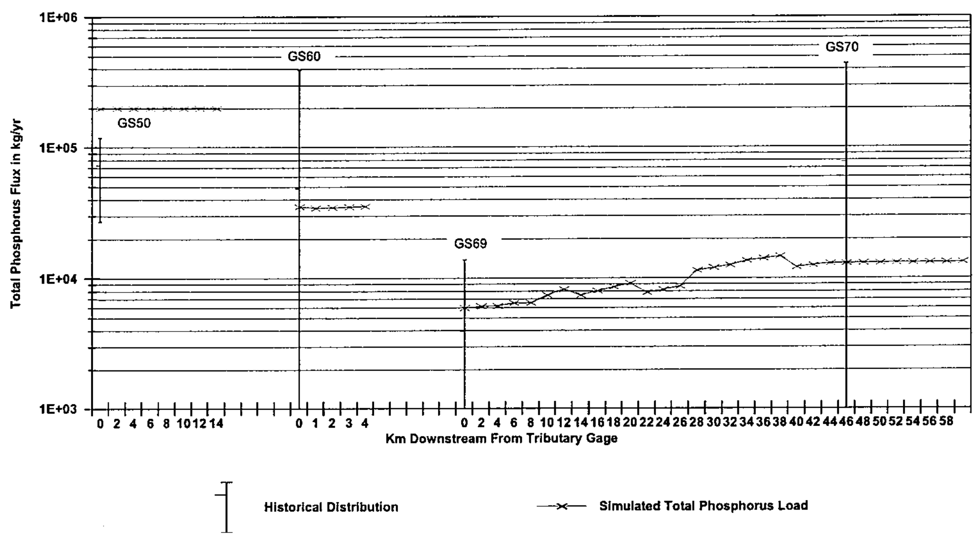

Figure 55. Results of Calibration of QUAL2EU Model with Historical Total Phosphorus Loading Data at Tributary Stations in the Illinois River Basin. Historical Data (WTRs 1980 - 1993) is Shown as the Mean Plus and Minus One Standard Deviation.

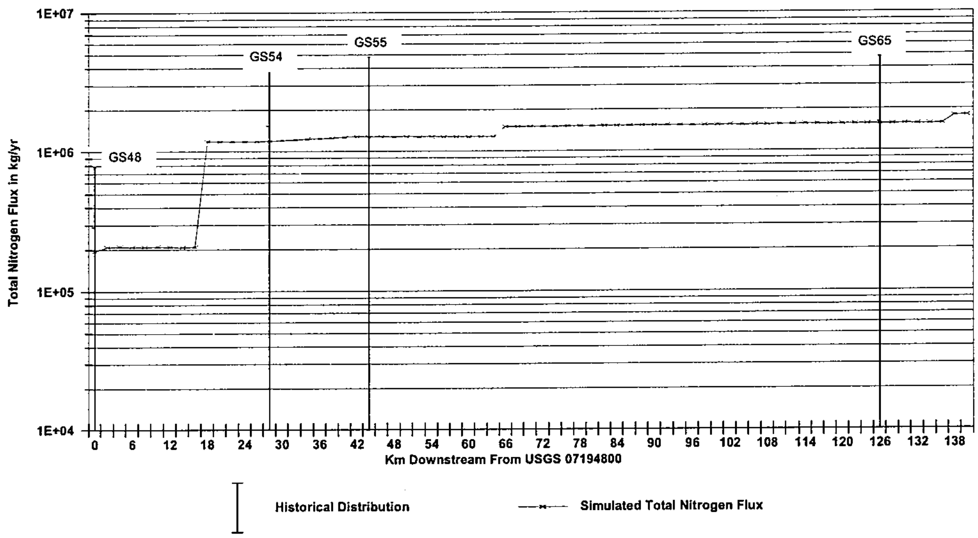

Figure 56. Results of Calibration of QUAL2EU Model with Historical Total Nitrogen Loading Data at Mainstem Stations on the Illinois River. Historical Data (WTRs 1980 - 1993) is Shown as the Mean Plus and Minus One Standard Deviation.

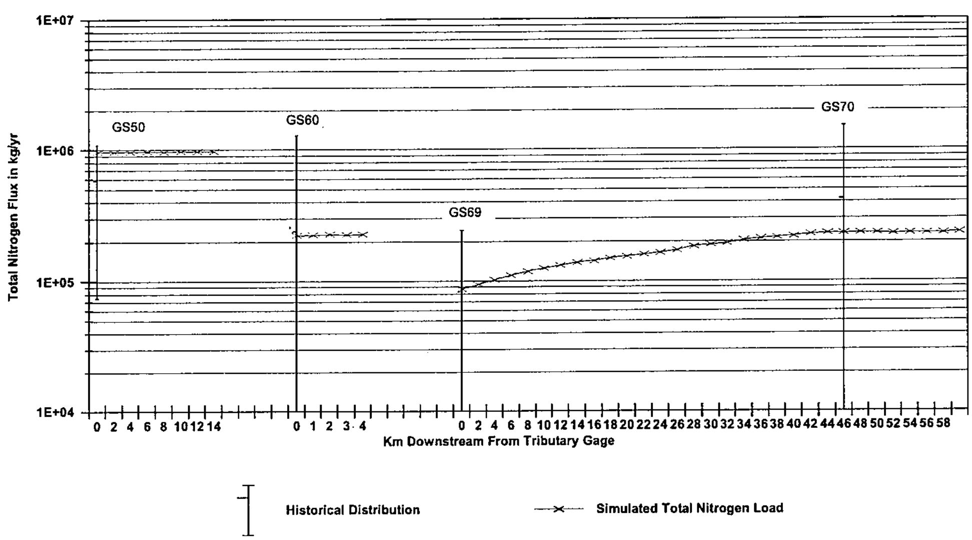

Figure 57. Results of Calibration of QUAL2EU Model with Historical Total Nitrogen Loading Data at Tributary Stations in the Illinois River Basin. Historical Data (WTRs 1980 - 1993) is Shown as the Mean Plus and Minus One Standard Deviation.

APPENDIX C

STANDARD CURVES, DATA, AND FIGURES ASSOCIATED WITH AUTOMATIC SAMPLING OF THE ILLINOIS RIVER AND BARON FORK CREEK

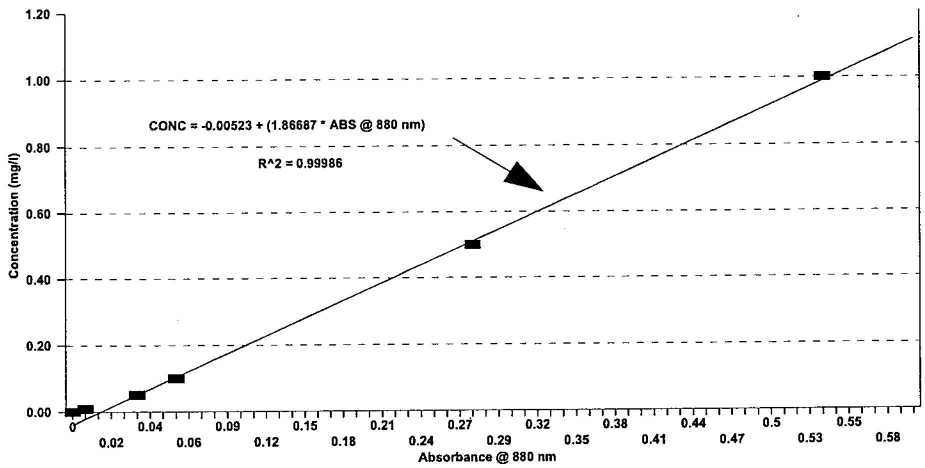

Figure 58. Standard Curve Developed for Analysis of Total Phosphorus Concentration in Automatic Sampler Observations.

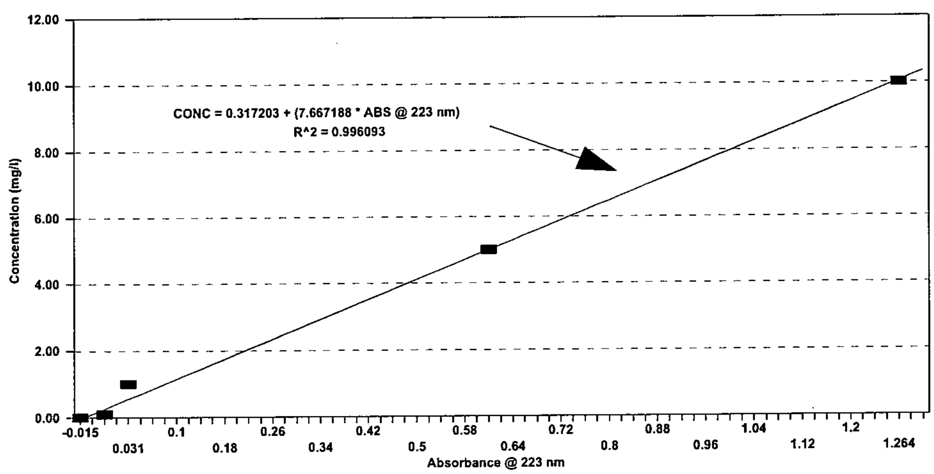

Figure 59. Standard Curve Developed for Analysis of Total Nitrogen Concentration in Automatic Sampler Observations.

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TABLE LXXIX

MEASURED CONCENTRATION AND DISCHARGE DATA FOR AUTOMATIC SAMPLING AT USGS 07196500 SEPTEMBER 10 - 12, 1993

Time	Discharge (cfs)	Total P (mg/l)	Total N (mg/l)
3:00 AM	648	0.114	1.64
6:00 AM	669	0.114	1.58
9:00 AM	739	0.126	1.55
12:00 PM	795	0.126	1.51
3:00 PM	823	0.134	1.57
6:00 PM	829	0.139	1.81
9:00 PM	829	0.163	1.84
12:00 AM	829	0.121	1.58
3:00 AM	818	0.119	1.45
6:00 AM	795	0.119	1.58
9:00 AM	783	0.119	1.60
12:00 PM	767	0.119	1.63
3:00 PM	739	0.121	1.58
6:00 PM	728	0.119	1.61
9:00 PM	706	0.116	1.60
12:00 AM	695	0.114	1.74
3:00 AM	690	0.119	1.57
6:00 AM	679	0.119	1.61
9:00 AM	669	0.114	1.64
12:00 PM	658	0.121	1.59

TABLE LXXX

MEASURED CONCENTRATION AND DISCHARGE DATA FOR AUTOMATIC SAMPLING AT USGS 07196500 SEPTEMBER 26 - 27, 1993

Time	Discharge (cfs)	Total P (mg/l)	Total N (mg/l)
3:36 AM	1,422	0.150	1.83
3:41 AM	1,470	0.150	1.63
5:41 AM	1,720	0.156	2.35
7:41 AM	1,930	0.160	1.91
9:41 AM	2,060	0.162	1.99
11:41 AM	2,130	0.168	1.86
1:41 PM	2,160	0.168	1.84
3:41 PM	2,170	0.173	1.77
5:41 PM	2,190	0.282	1.60
7:41 PM	2,220	0.173	1.95
9:41 PM	2,230	0.191	1.99
11:41 PM	2,230	0.185	1.89
1:41 AM	2,230	0.264	2.06
3:41 AM	2,220	0.244	1.72
5:41 AM	2,170	0.185	1.81
7:41 AM	2,120	0.168	1.84
9:41 AM	2,050	0.152	1.72
11:41 AM	2,000	0.162	1.75
1:41 PM	1,950	0.146	1.78
3:41 PM	1,910	0.150	1.59
5:41 PM	1,870	0.156	1.56
7:41 PM	1,830	0.148	1.67
9:41 PM	1,810	0.140	1.62

TABLE LXXXI

MEASURED CONCENTRATION AND DISCHARGE DATA FOR AUTOMATIC SAMPLING AT USGS 07196500
OCTOBER 21 - 22, 1993

Time	Discharge cfs	Total P mg/l as P	Total N mg/l as N
12:00 AM	1,450	0.113	2.37
12:30 AM	1,470	0.115	2.19
1:00 AM	1,490	0.113	2.46
3:00 AM	1,570	0.125	2.28
5:00 AM	1,670	0.125	2.72
7:00 AM	1,890	0.131	2.55
9:00 AM	2,180	0.151	3.17
11:00 AM	2,450	0.179	2.81
1:00 PM	2,630	0.201	2.55
3:00 PM	2,780	0.209	2.81
5:00 PM	2,850	0.215	2.90
7:00 PM	2,910	0.227	2.72
9:00 PM	2,930	0.223	2.64
11:00 PM	2,930	0.233	2.46
1:00 AM	2,930	0.233	2.81
3:00 AM	2,850	0.221	2.10
5:00 AM	2,780	0.274	3.02
7:00 AM	2,670	0.167	2.46
9:00 AM	2,590	0.195	2.64
11:00 AM	2,500	0.181	2.46
1:00 PM	2,410	0.171	3.26
3:00 PM	2,320	0.169	2.99

TABLE LXXXII

MEASURED CONCENTRATION AND DISCHARGE DATA FOR AUTOMATIC SAMPLING AT USGS 07197000 AUGUST 25 - 26, 1993

Time	Discharge (cfs)	Total P (mg/l)	Total N (mg/l)
8:00 AM	84	0.660	3.67
11:00 AM	106	0.178	2.81
2:00 PM	108	0.156	3.52
5:00 PM	106	0.129	3.09
8:00 PM	99	0.104	2.99
11:00 PM	90	0.111	2.91
2:00 AM	86	0.104	2.95
5:00 AM	82	0.099	2.89
8:00 AM	78	0.092	2.90
11:00 AM	78	0.097	2.97
2:00 PM	72	0.075	2.12
5:00 PM	67	0.072	2.08

TABLE LXXXIII

MEASURED CONCENTRATION AND DISCHARGE DATA FOR AUTOMATIC SAMPLING AT USGS 07197000 OCTOBER 16 - 18, 1993

Time	Discharge (cfs)	Total P (mg/l)	Total N (mg/l)
7:30 PM	1,250	0.280	1.66
7:45 PM	1,660	0.369	2.00
8:00 PM	2,050	0.615	2.32
8:15 PM	2,425	1.327	3.59
9:30 PM	3,965	1.002	4.41
11:30 PM	4,805	0.576	3.68
1:30 AM	4,420	0.505	3.39
3:30 AM	3,875	0.400	2.65
5:30 AM	3,985	0.436	2.44
7:30 AM	4,155	0.392	2.46
9:30 AM	4,030	0.227	2.49
11:30 AM	3,650	0.268	1.78
1:30 PM	3,300	0.233	2.07
3:30 PM	3,000	0.215	2.06
5:30 PM	2,760	0.179	1.97
7:30 PM	2,585	0.168	2.25
10:30 PM	2,350	0.162	2.04
12:30 AM	2,225	0.150	1.92

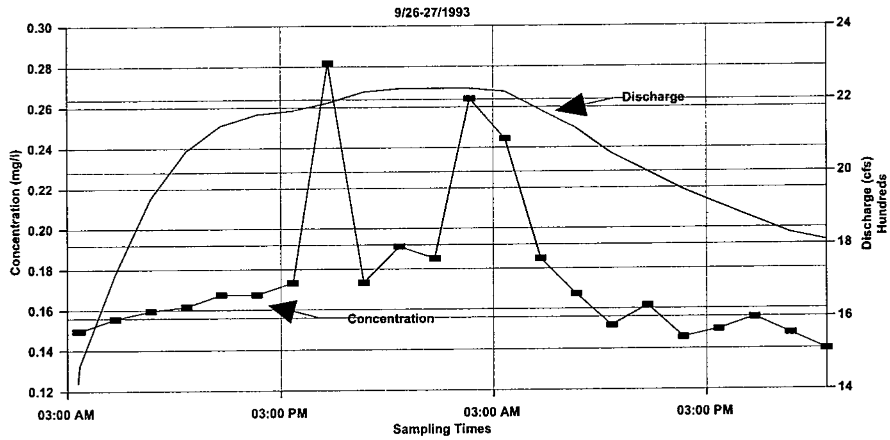

Figure 60. Measured Total Phosphorus Concentration and Discharge at USGS 07196500 September 26 - 27, 1993.

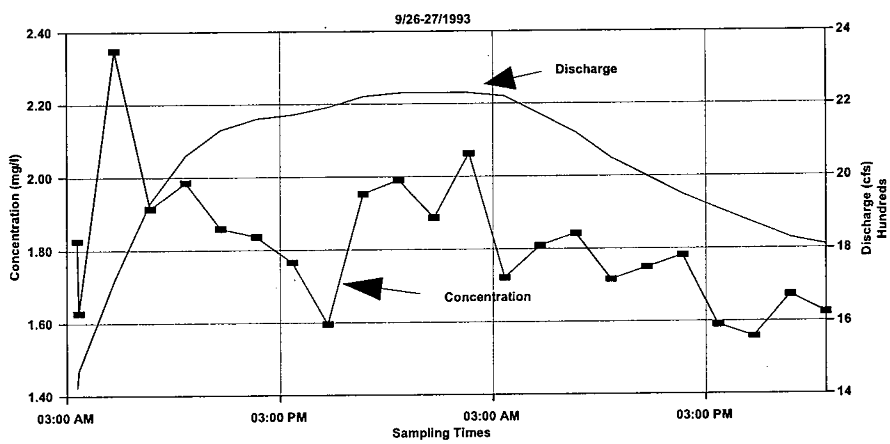

Figure 61. Measured Total Nitrogen Concentration and Discharge at USGS 07196500 September 26 - 27, 1993.

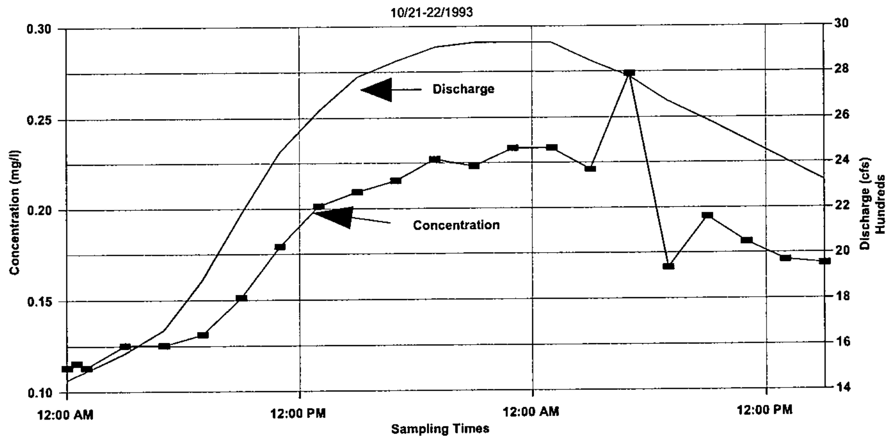

Figure 62. Measured Total Phosphorus Concentration and Discharge at USGS 07196500 October 21 - 22, 1993.

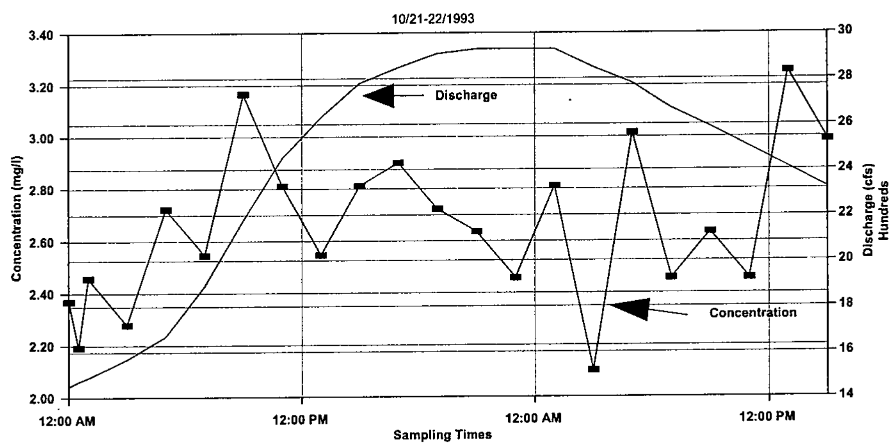

Figure 63. Measured Total Nitrogen Concentration and Discharge at USGS 07196500 October 21 - 22, 1993.

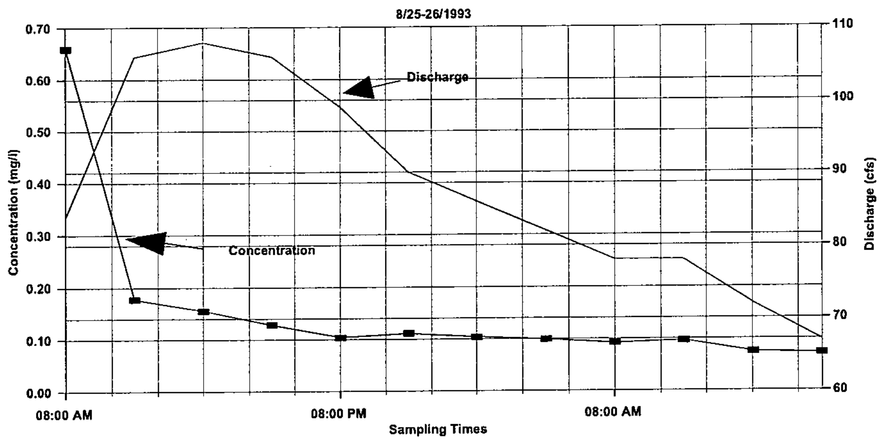

Figure 64. Measured Total Phosphorus Concentration and Discharge at USGS 07197000 August 25 - 26, 1993.

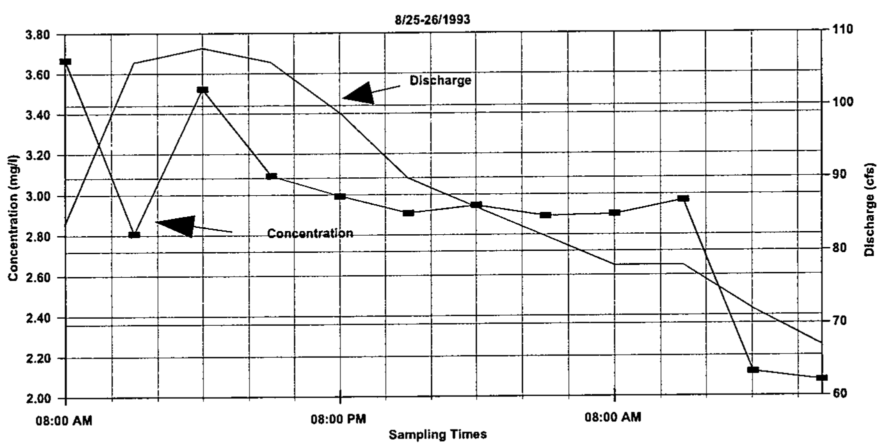

Figure 65. Measured Total Nitrogen Concentration and Discharge at USGS 07197000 August 25 - 26, 1993.

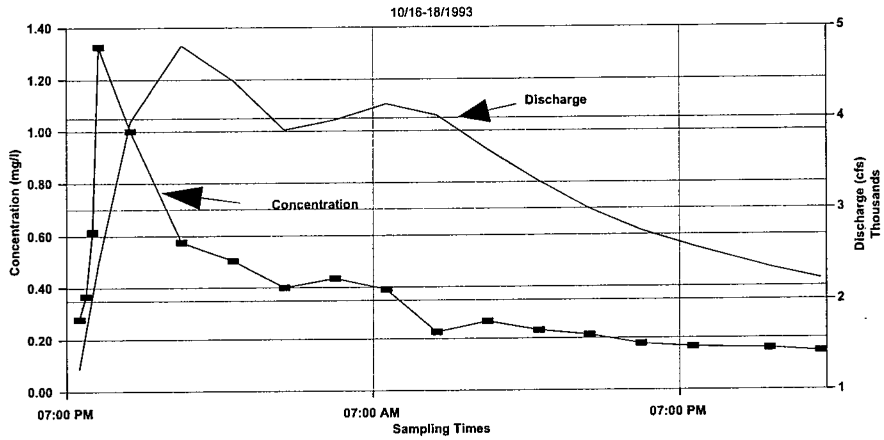

Figure 66. Measured Total Phosphorus Concentration and Discharge at USGS 07197000 October 16 - 18, 1993.

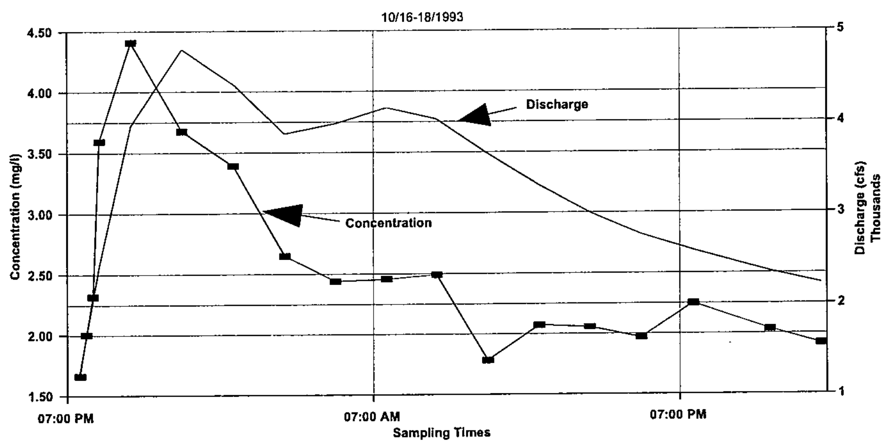

Figure 67. Measured Total Nitrogen Concentration and Discharge at USGS 07197000 October 16 - 18, 1993.